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SOURCE TESTING CODE

(Version #2)

Report # ARB-66-80

November 1980

Environment
Environnement
Ontario

Errata

On page 5-21

(1) Where it says: "The smallest practical nozzle is .9 mm (0.187 inch) in diameter."

   It should say: "The smallest practical nozzle is 4.69 mm (0.187 inch) in diameter."

(2) Where it says:

$$\Delta H = \left(\frac{60(85.35)(\pi) D_N^2 C_p}{4(144)} \right)^2 \frac{(1 - B_{wo}) M_d T_{m(avg)} P_s \Delta P}{K_o^2 M_s T_{s(avg)} P_m} \quad \text{eq. } 5(11)$$

It should say:

$$\Delta H = \left(\frac{60(85.35)(\pi) D_N^2 C_p}{4(144)} \right)^2 \frac{(1 - B_{wo})^2 M_d T_{m(avg)} P_s \Delta P}{K_o^2 M_s T_{s(avg)} P_m} \quad \text{eq. } 5(11)$$

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Air Resources Branch
Ontario Ministry of the Environment

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Cette publication technique
n'est disponible qu'en anglais.

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METHOD 4 - DETERMINATION OF MOISTURE CONTENT OF STACK GASES

METHOD 5 - DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

INTRODUCTION

This code has been formulated to specify methods for the measurement of emissions of air pollutants from stationary sources when such emission data are required for the purpose of determining compliance with the Environmental Protection Act of the Province of Ontario and the regulations thereunder.

These methods contain the most reliable technical procedures available at the date of issue. However, as new and better techniques are accepted, the methods will be revised, replaced or supplemented accordingly and the code will be appropriately amended. If a method for determination of a particular pollutant is not included in this code, the Ministry of the Environment should be contacted in order to select a satisfactory measurement method.

Prior to implementing any of the methods described in this code, it is recommended that the introductory material titled: "Conducting A Source Sampling Test", be carefully reviewed. Outlined therein are the requirements concerning the operating conditions of the process and pollution abatement facilities of the source being sampled, the proper planning and execution of a source sampling test, the desirable qualifications of sampling personnel and the requirements for a satisfactory source testing report. The requirements which must be met when the use of an alternative testing method is planned are described as well.

This report, version #2, replaces in entirety the earlier Ontario Source Testing Code, version #1, published in January 1973.

CONDUCTING A SOURCE SAMPLING TEST

A source sampling test is performed in order to measure the emissions of an air pollutant from an industrial operation. The rate and magnitude of these emissions vary with changes in the production rate and the process control and pollution abatement device operating parameters. It is, therefore, crucial for the proper interpretation of the test results that all parameters affecting the emissions be closely monitored during the execution of a source sampling test. Furthermore, in the case of a compliance test, these parameters must be maintained and controlled as described in the definition of compliance testing.

1.   PRE-TEST INFORMATION

Prior to source testing, the source testing supervisor (See p. 9) must tour the plant in order to familiarize himself with the process and to collect and evaluate the pre-test information. From the evaluation of this information, he will be able to define the process conditions which must be maintained during the test and the modifications required at the sampling site to carry out a proper source test. His conclusions and recommendations regarding these matters should be discussed with the production personnel and the responsible Ministry official. If deemed necessary by the parties involved, a pre-test meeting may have to be arranged in order to resolve any potential problems and to ensure a mutually satisfactory sampling program.

The pre-test information includes the following:

a)   Source Process Information

process parameters:

(1)   mode of operation (cyclic, batch or continuous)
(2)   feed rates and composition
(3)   fuel rates and composition
(4)   normal operating temperatures
(5)   specific process parameters affecting emissions

stack parameters:

(6)   physcial dimensions and layout of the stack
(7)   volumetric stack gas flowrate

stack gas parameters:

(8)   normal stack gas temperature

(9)   estimated stack gas composition and moisture content

(10)   physical and chemical nature of the pollutants

(11)   expected concentrations of particulate and gaseous pollutants

b)   Test Area Information

The source testing supervisor will personally inspect the physical characteristics of the source in order to evaluate potential test locations, considering such factors as:

(1)   safety and shelter of team personnel

(2)   accessibility of the sampling site

(3)   sampling platform space and scaffolding requirements

(4)   availability of necessary power sources

2.   SOURCE TEST REPORTING

The source testing supervisor will ensure that all pertinent process information is recorded during testing. He will be able to inform the Ministry Official on the status of the process at any time during the performance of the source tests.

All source testing reports submitted to the Ministry must contain the information required in each of the relevant methods and appendices. This information must be presented in a form similar to the demonstrated examples. These data include:

a)   preliminary survey data and results

b)   velocity traverse data sheets and results

c)   volumetric stack gas flow rate results

d)   stack gas composition data sheet and results

e)   stack gas molecular weight results

f)   stack gas moisture data sheet and results

g)   particulate matter traverse data sheet, particulate matter analysis sheet, moisture data sheet and particulate matter emission rate results

h)   gaseous matter sampling data sheet, gaseous matter analysis sheet, moisture data sheet and gaseous matter emission rate results

i)   process operation and production data

j)   pollution abatement equipment operating data

k)   calibration data

The following summary sheet must be submitted for each test of a particulate pollutant sampling programme:

1)   COMPANY NAME:

2)   CITY:

3)   LOCATION:

4)   TEST #, DATE:

5)   PRODUCTION: (e.g. tons/hr)

6)   BAROMETRIC PRESSURE: (inches Hg)

       STATIC PRESSURE: (inches H_2O)

       PITOT TUBE COEFFICIENT:

       METER CORRECTION FACTOR:

       NOZZLE DIAMETER: (inches)

       STACK DIMENSIONS: DIAMETER (D) (inches); LENGTH (L)(inches); WIDTH (W) (inches)

       $\%CO_2$_____, $\%O_2$_____, $\%CO$_____, $\%SO_2$_____

7)   NO. OF READINGS:

       TIME BETWEEN READINGS:

       TEST POINTS/TRAVERSE:

       NO. OF TRAVERSES:

       CONDENSED WATER: (grams)

       WATER CAUGHT BY DRYING AGENTS: (grams)

       NO. OF POLLUTANTS:

8)   POLLUTANT NAMES: (a)

                         (b)

                         (c)

                         (d)

9)   (a) PROBE:____,CYCLONE:____,FILTER:____,IMPINGER:____(mg)

       (b) PROBE:____,CYCLONE:____,FILTER:____,IMPINGER:____(mg)

       (c) PROBE:____,CYCLONE:____,FILTER:____,IMPINGER:____(mg)

       (d) PROBE:____,CYCLONE:____,FILTER:____,IMPINGER:____(mg)

The following summary sheet must be submitted for each test of a gaseous pollutant sampling programme:

1) COMPANY NAME:
2) CITY:
3) LOCATION:
4) TEST #, DATE:
5) PRODUCTION: (e.g. tons/hr)
6) BAROMETRIC PRESSURE: (inches Hg)
   STATIC PRESSURE: (inches H_2O)
   PITOT TUBE COEFFICIENT:
   METER CORRECTION FACTOR:
   NOZZLE DIAMETER: (inches)
   STACK DIMENSIONS: DIAMETER (D) (inches); LENGTH (L)(inches); WIDTH (W) (inches)
   %CO_2_____, %O_2_____, %CO_____, %SO_2_____
   MOISTURE FRACTION (B_{wo}):
7) NO. OF READINGS:
   TIME BETWEEN READINGS:
   TEST POINTS/TRAVERSE:
   NO. OF TRAVERSES:
   CONDENSED WATER: (grams)
   WATER CAUGHT BY DRYING AGENTS: (grams)
   NO. OF POLLUTANTS:
   NO. OF IMPINGERS:
8) VOLUME OF TITRANT: (ml)
   NORMALITY: (ml)
   VOLUME OF BLANK TITRATED: (ml)
   VOLUME OF TOTAL SAMPLE: (ml)
   VOLUME OF SAMPLE TITRATED: (ml)
9) EQUIVALENT WEIGHT OF GAS: (e.g., SO_2=32, HCl=36.5, Cl_2=35.5)
10) SAMPLING METHOD: (continuous or grab sample)
11) COMPONENT NAME:

Generally, a source testing report should be organized as follows:

1) Title page
   - main title - location of source
   - subtitle - pollutants sampled for
   - identification of key members of source testing group or consulting organizations
   - date of completion of report

2) Summary page
   - abstract of report summarizing purpose, scope, method, results and conclusions

3) Table of Contents

4) List of Figures

5) List of Tables

6) Background

7) Description of the source
   - location of process and description of process operation and pollution abatement equipment
   - correlation between process operation and sampling scheduling

8) Test Procedures
   - description of sampling equipment
   - description of sampling site, ports and points (diagrams)
   - description of sampling procedure, noting special adaptations
   - description of sample recovery and analysis

9) Results and Discussion
   - results summarized in tabular form
   - discussion concerning validity and applicability of the results

10) Conclusions and Recommendations

11) Appendices
   - preliminary and test series raw data and calculations
   - laboratory analysis and descriptions of analytical methods
   - calibration data
   - production data
   - pollution abatement equipment operating data

3.   SOURCE SAMPLING METHODS

This code comprises various methods which describe the apparatus and techniques used to conduct source sampling tests. The first four methods - location of sampling site and sampling points, measurement of velocity and volumetric flow rate, determination of dry gas molecular weight and moisture content - are required, all or in part, to be performed in conjunction with the further methods which deal with measuring the concentrations of specific pollutants. However, these four methods are often performed simultaneously, e.g., in conducting a Method 5 particulate test, a velocity traverse and a moisture content determination are included as part of the procedure of that method.

Limitations on the applicability of the methods are stated and suitable elaboration is appended to each method. Any method which relies on or incorporates another method is subject to the same limitations as that other method.

The errors involved in application of all the methods described in this code are, in most cases, random in nature and will vary from source to source and from sampling team to sampling team. The computation procedure for estimation of these random errors is given in the literature[1].

In addition to these random errors, errors of bias may be associated with methods for specific pollutants due to either poor collection efficiencies or errors associated with the analytical techniques. If such errors exist, they are discussed in the description of the individual methods.

The methods in this code are reference methods and every effort should be made to use the apparatus and procedures described therein. However, the use of an alternative method may be justifiable but it must be shown to produce results equivalent to the reference method. Demonstration of this equivalency usually involves the performance of specifically designed experiments which should provide adequate information to resolve issues such as the following:

1)   equivalent results obtained at all concentrations anticipated during
       compliance testing;

2)   equivalent results obtained at process and stack gas conditions expected
       during compliance testing;

3)   equivalent results obtained when the reference and alternative apparatus

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[1] Brenchley, D.L., Industrial Source Sampling, Ann Arbor Science Publishers, Inc., Ann Arbour Michigan, 1973.

are positioned at the same point at the sampling site;

4) effect of stack gas components which interfere with the operation of the alternative technique;

5) equivalent reliability of results when the reference procedure is modified, e.g., fewer sampling points and/or less sampling time.

Once such experiments have been performed, having analysed all relevant factors, documented proof of equivalency should be submitted to the Provincial Officer for approval of the alternative method.

4. LIMITATIONS

It is recognized that there will be many processes and situations which may limit the application of the methods described in this code. Specifically, caution must be exercised when dealing with any of the following:

a) corrosive or highly reactive components

b) high vacuum or pressure

c) high gas temperature

d) high gas moisture content

e) high and low gas velocity

f) very small and very large duct cross-sections

g) complex flow patterns

h) fluctuations in velocity, particulate loading, and temperatures, due to uncontrollable process variations

Reference can be made to the appendices for possible solutions to some of the problems noted above. Where specific limitations are set out in a method, reference should first be made to the appendices of the method and, if there is no solution proposed, the problem should be discussed with the Provincial Officer.

5. SOURCE SAMPLING TEAM

Ideally, a source sampling team consists of no less than three persons to perform the tests at the sampling site and to record the required data. One person of the three shall be the source testing supervisor, who will ensure that sampling is conducted properly and that the process is operating at the maximum production rate.

When sampling the emissions from a cyclic or batch charging process, a fourth sampling team member may be required to obtain data detailing the operating conditions while the sampling is taking place.

The source testing supervisor should have a relevant university degree (e.g., chemical, mechanical, or environmental engineering, or science) and/or sufficient experience and understanding of industrial processing and source testing to perform activities outlined in this introduction. Individuals with no previous experience in source testing must successfully complete a suitable source sampling course followed by a two week period of observing source sampling in the field.

One of the remaining members of the source testing team should have sufficient experience to prepare and operate source sampling trains in a competent manner. He should have successfully completed a source sampling course and had some previous experience in source testing.

6. DEFINITIONS

Compliance Test - A source test conducted for the purpose of determining compliance with the Environmental Protection Act of Ontario or the regulations promulgated thereunder, performed and reported in accordance with the requirements of this code. The Ministry must be advised of any proposed compliance testing prior to setting any firm testing schedule and supplied with relevant process and test information. If required, a Ministry official must be allowed to tour the process, inspect the sampling site and witness the sampling tests. It must be demonstrated that the testing was performed at process conditions effecting the maximum pollutant emissions, e.g., at normal maximum production rates excluding process upsets, and that the test results truly represent the emissions from this source. An acceptable final report must be submitted to the Ministry.

Condensible Material - All moisture and other materials which are condensed in the impinger train.

Corrosive Source - An enclosed gas stream containing components which would attack the metal or filter surfaces of the sampling equipment under sampling conditions.

Enclosed Gas Stream - Any flow of gas contained within a duct or stack.

High Moisture Content Source - A gas stream which is saturated or supersaturated with water.

High Pressure Source - An enclosed gas stream in which the absolute pressure is in excess of 1 kPa (4 in.H_2O) above atmospheric pressure.

High Temperature Source - An enclosed gas stream in which the temperature is in excess of $600^{\circ}C$ ($1100^{\circ}F$).

High Vacuum Source - An enclosed gas stream in which the absolute pressure is less than atmospheric pressure by at least 1 kPa (4 in. H_2O).

High Velocity Source - Velocity of an enclosed gas stream greater than 30 m/s (110 ft/s).

Highly Reactive Source - An enclosed gas stream containing unstable components which easily react to form other chemical components in the sampling equipment which would cause inherent errors in sampling and analysis.

Isokinetic Sampling - The sampling velocity at the nozzle opening is matched with that of the gas stream at the sampling point in order to minimize both flow disturbances introduced by the probe and sampling errors due to the inertial effects of particles.

Low Velocity Source - A velocity of an enclosed gas stream less than 3 m/s (10 ft/s). This would normally exclude the duct boundary layer.

Particulate Concentration - The weight of particulate matter per unit volume of gas in the enclosed gas stream.

Particulate Mass Flow - The weight of particualte matter flowing in the enclosed gas stream per unit time.

Particulate Matter - All those components of the enclosed gas stream which, when sampled according to the methods of this code, are retained by the probe, cyclone and filter assemblies, which are maintained at a temperature of $120^{\circ}C$ ($248^{\circ}F$); any material collected in the impinger train is not included as particulate matter unless previously agreed upon by the Provincial Officer.

Reference Conditions -   101.3 kPa, $298^{\circ}K$
                              29.92 in. Hg, $537^{\circ}R$

APPENDIX 1: Sampling Under Adverse Conditions

The essential requirement for any source test is that the sample must be representative of the whole from which it is taken. Various conditions (listed under "Limitations") may affect this criterion. The following are some suggested ways to overcome these adverse conditions:

a) Corrosive or Highly Reactive Components - The use of special materials such as Inconel*, glass, quartz or Teflon**.

b) High Vacuum Sources - (found before exhaust fans and high natural draft stacks) Operation of sampling train pump before and after probe insertion to avoid escaping of the impinger solution into the filter holder; gas volume drawn before and after insertion should not be included in sample volume.

c) High Pressure Sources - Port sealed tightly yet allowance for freedom of movement of the probe; e.g., gas valve and packing gland incorporated in port.

d) High Temperature Source - Quartz or Inconel* probe liner or water cooled probe with temperature control to avoid cooling below dew point; shielded and aspirated thermocouple.

e) High Moisture Content Source - Probe temperature maintained above the dew point; probe sheathed with insulation layer within an outer layer to prevent droplets from impinging on the actual probe, creating cooling via evaporation; locate filter between third and fourth impinger (Method 5).

f) High Velocity Source - Sampling site is relocated or duct or stack expanded to reduce velocity; pumps of sufficient capacity to maintain the required sampling rates are used.

g) Low Velocity Source - In the range of 1.5 - 3.0 m/s (5-10 ft/s) an inclined manometer with a scale of 0 to 0.6 kPa (0 - 2.4 in.H_2O) is used; below 1.5 m/s (5 ft/s), sampling site is relocated or the duct constricted to increase the velocity.

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*   Trade Mark - Huntingdon Alloy Products Division; The International Nickel Co. Inc.

**   Trade Mark - E.I. DuPont de Nemours & Co.

NOTE: The following methods have been written to allow for calculations in both the SI and the British systems. However, at present, most types of sampling equipment present data in British units. To reflect this fact, the sample reports and sample calculations in the methods demonstrate only British units. It is assumed that eventually equipment manufacturers will change to the SI system and at such time appropriate revisions will be made to this code.

METHOD 1

LOCATION OF SAMPLING SITE AND SAMPLING POINTS

METHOD 1
LOCATION OF SAMPLING SITE AND SAMPLING POINTS

1.   PURPOSE

To determine sampling site and number of sampling points and their location based on stack or duct configuration.

2.   LIMITATIONS

The basic method is not applicable in the following cases:

i)   cyclonic flow

ii)   reverse flow

iii)   stack or duct diameter less than 0.15 m (0.5 ft) or greater than 5.0 m (16 ft)

iv)   non-circular and non-rectangular stack or duct cross-section

Where any of the above situations occur, reference should be made to the appendices (p. 1-10).

3.   EQUIVALENT DIAMETER FOR RECTANGULAR CROSS - SECTIONS

equivalent diameter, $D_e = \dfrac{2LW}{L+W}$ eq.1(1)

where L = length
    W = width

Reference herein to "diameter" includes both diameter of a circular cross-section and equivalent diameter of a rectangular cross-section.

4.   LOCATION OF SAMPLING SITES

i)   The preferred location of the site is found in a straight, vertical length of stack or duct, close to the point of emission into the atmosphere, at least 8 diameters downstream and at least 2 diameters upstream from any flow disturbance. Deviation from the preferred location is acceptable within the limitations and compensations stated in this method.

ii)   For a stack or duct of circular cross-section, at least two sampling ports, separated by 90°, are required. Where applicable, the diameter passing through one port should be parallel to the centre line of an upstream flow disturbance and the other diameter should be perpendicular to this centre line.

iii)   For a rectangular cross-section, ports are located on the most convenient face of the stack or duct. Their number corresponds to the number of traverses required to sample at the requisite number of points, as calculated herein.

5.   TOTAL NUMBER OF SAMPLING POINTS

i)   In the case where the sampling site is located at least 8 diameters downstream and 2 diameters upstream from a flow disturbance, the required minimum number of sampling points for a circular or rectangular cross-section is determined according to Tables 1 and 2.

ii)   For sites with circular cross-sections, the total number of sampling points is divided evenly between 2 traverses, the traverses being performed in directions perpendicular to each other.

iii)   For sites with rectangular cross-sections, the equivalent diameter, D_e, is used as the diameter for the purposes of determining the minimum total number of sampling points. When the number is determined from Table 1, it is compared to the figures given for the total number of sampling points in Table 2 and, where necessary, the number is increased to the next greater figure in Table 2. In the column titled "Number of sampling points per traverse and number of traverses", it is a matter of convenience as to which number represents traverses and which represents sampling points.

If the ratio of length to width of the cross-section is greater than 1.5, the layouts of Table 2 are not applicable. In that case the number of traverses and number of sampling points should be chosen such that their ratio most closely approximates the stack or duct dimensional ratio and provides at least the required minimum number of points.

iv)   In situations where the sampling sites are not located at least 8 diameters downstream and 2 diameters upstream from a flow disturbance, the required minimum total number of sampling points is determined by multiplying the number of sampling points, from Table 1, by a multiple determined from Figure 1. Multiples corresponding to the number of diameters that the sampling site is downstream and upstream from a disturbance are determined and the greater of these multiples is used to determine the required minimum total number of sampling points.

In the case of rectangular cross-sections, the required number of points is compared to the figures in Table 2 and, where necessary, converted as in subsection (iii). In the case of circular cross-sections, the required number of points, if not equal to a multiple of 4, must be increased to the next greater multiple of 4.

TABLE 1	
Minimum number of sampling points at a site 8 diameter downstream and 2 diameters upstream of a flow disturbance.	
Inside diameter of circular stack or duct or equivalent diameter	Minimum number of sampling points
meters feet	
I.D. $\leq$ 0.3 I.D. $\leq$ 1	4
0.3 < I.D. $\leq$ 0.6 1 < I.D. $\leq$ 2	8
0.6 < I.D. $\leq$ 1.3 2 < I.D. $\leq$ 4	12
1.3 < I.D. $\leq$ 2.5 4 < I.D. $\leq$ 8	20
2.5 < I.D. $\leq$ 5.0 8 < I.D. $\leq$ 16	32
5.0 < I.D. 16 < I.D.	

TABLE 2	
Cross-sectional layout for rectangular stack or duct.	
Number of sampling points	Number of sampling points per traverse and number of traverses
4	2 x 2
9	3 x 3
12	3 x 4
16	4 x 4
20	4 x 5
25	5 x 5
30	5 x 6
36	6 x 6
42	6 x 7
49	7 x 7
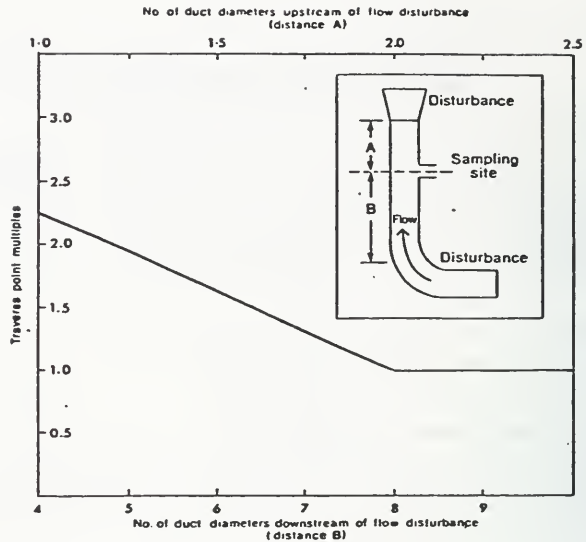
FIGURE 1.   Multiples to determine minimum number of
             sampling points required when A<2
             or B<8.

v)   When the ratio of velocities at any two points (excluding the boundary layer
near the stack wall) differ by more than 2:1, the total number of sampling points,
as determined from Tables 1 and 2, must be doubled, or the maximum sampling
point multiple in Figure 1 used.

6.   LOCATION OF SAMPLING POINTS

        Sampling points are located at the centroid of equal areas of the cross-
section of the stack or duct.

i)   For a circular cross-section, half the total number of points are located on
each traverses, the spacing being determined by reference to Table 3 or the
following subsection. An example of a grid of sampling points is shown in Figure 2.
The figures in Table 3 have been calculated from the following equations. These
equations may be used to extrapolate the table.

For points from the port to centre:

$$R = 100(0.5 - \sqrt{\frac{2n-1}{4N}})$$ eq. 1(2)

$$n = \frac{N}{2} + (1-h)$$ eq. 1(3)

where   R = percentage of stack or duct diameter from port
        h = sampling point number (from port)
        N = number of sampling points per traverse

For points from the centre to the far wall:

$$R = 100(0.5 + \sqrt{\frac{2n-1}{4N}})$$ eq. 1(4)

$$n = h - \frac{N}{2}$$ eq. 1(5)

where   R = percentage of stack or duct diameter from port
        h = sampling point number (from port)
        N = number of sampling points per traverse

ii)   For rectangular cross-sections, the area is divided into as many equal rectangular sections as there are sampling points. These sections are laid out according to the numbers in the right-hand column of Table 2 or as described in 5 (iii). Sampling points are located at the centroid of these areas.

iii)   For circular stacks of diameter greater than 0.6 m (2.0 ft), if a sampling point is located within 2.5 cm (1.0 in.) of a wall, it must be relocated from the wall a distance of 2.5 cm (1.0 in.). For stacks of diameter less than 0.6 m (2 ft), if a sampling point is located within 1.3 cm (0.5 in.) of a wall it must be relocated at a distance of 1.3 cm (0.5 in.)from a wall. If a relocated point coincides with another sampling point then the sampling time is doubled at that point. It is assumed that this problem will not occur with rectangular cross-sections.

7.   CYCLONIC FLOW CONFIRMATION

If the presence of cyclonic flow is suspected, it is verified by the following procedure:

i)   Level and zero a manometer.

ii)   Position an S-type pitot at a sampling point so that the planes of the face openings are parallel to the longitudinal axis of the stack or duct.

iii) Rotate the pitot (up to $\pm$ 90°) about its longitudinal axis until the manometer reading ΔP is zero. Record the angle to the nearest degree. If the pitot does not have to be rotated to produce zero ΔP then an angle of 0° is recorded. This procedure is repeated for each sampling point.

iv)   Average the recorded angles; if the average is less than 10°, sampling may proceed as normal; if it is greater than 10°, cyclonic flow is confirmed.

8.   REVERSE FLOW CONFIRMATION

Reverse flow is confirmed if, at any sampling site, there are one or more sampling points at which a negative velocity pressure head is found.

9.   DISCUSSION OF METHOD 1

Purpose

This method is used to ensure collection of representative samples of particulate pollutants and to measure stack gas velocities by the use of other methods described later.   More particularly, procedures are described for determination of a preferred sampling site on the duct or stack and for determination of the total number of sampling points required at that site. The procedures outlined here account for flow disturbances and various duct or stack configurations. Procedures are also provided to increase the number of sampling points where a non-ideal sampling site must be used. This method applies (within the stated limitations) to all stacks and ducts, vertical and horizontal, with circular or rectangular cross-sections.

Limitations

Cyclonic flow must be suspected in such cases as: after devices such as in-line turbine fans, cyclones, inertial demisters following venturi scrubbers, and in stacks or ducts having tangential inlets or configurations which tend to induce swirling. The procedure in the section on cyclonic flow configuration is followed to verify the absence of such flow. If cyclonic flow is found, the overall flow is indeterminate and Method 1 should not be applied. Please refer to the appendices. Reverse flow must be suspected in cases where there is an obstruction in the stack

or duct (e.g., baffle plates) upstream of the sampling site. If a negative velocity pressure head is detected, reverse flow is confirmed and Method 1 should not be applied. In such situations reference to the appendices should be made.

Flow disturbances in a stack or duct include: bends, constrictions, expansions, fans, turning vanes, air-cleaning equipment, visible flames, hoppers, exits, etc. Beyond the stated limitations of this method, flow conditions may be indeterminant and collected data are unreliable.

Location of Sampling Sites

In order to obtain a representative measurement of a flow parameter, the overall sampling conditions must be stable. This criterion can be best met when there is a steady and relatively uniform velocity profile. In order to achieve this profile, the effect of disturbances must be minimized. The preferred site location is 8 or more diameters downstream from a disturbance and 2 or more diameters upstream from a disturbance. It is assumed that the effects of the disturbances will be minimal at these distances. If a less than preferable location must be used, increasing the number of sampling points should result in collection of more accurate data.

A vertical stack is preferred, especially with respect to particulate sampling, since gravity could cause stratification of particles at non-vertical sites. Traverses must be conducted in 2 perpendicular directions when testing at stacks or ducts with circular cross-sections. Furthermore, one traverse should be parallel and the other perpendicular to the centreline of an upstream flow disturbance. These procedures are employed for two reasons: 1) to determine the uniformity of the flow across the entire cross-section and, 2) to provide a more accurate measurement of the flow parameters.

TABLE 3   LOCATION OF TRAVERSE POINTS ON DIAMETERS OF CROSS-SECTIONS OF CIRCULAR STACKS

TRAVERSE POINT NUMBER ON A DIAMETER	PERCENT OF STACK DIAMETER FROM INSIDE WALL TO TRAVERSE POINT											
	Number of traverse points on a diameter											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.3	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.7	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.5	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.5	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.3	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.5	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.5	36.6	28.3	23.6	20.4	18.0	16.1
8				96.7	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.1	23.0
10					97.5	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.9	67.7
15								95.1	89.1	83.5	78.2	72.8
16								98.4	92.5	87.1	82.0	77.0
17									95.6	90.3	85.4	80.6
18									98.6	93.3	88.4	83.9
19										96.1	91.3	86.8
20										98.7	94.0	89.5
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9
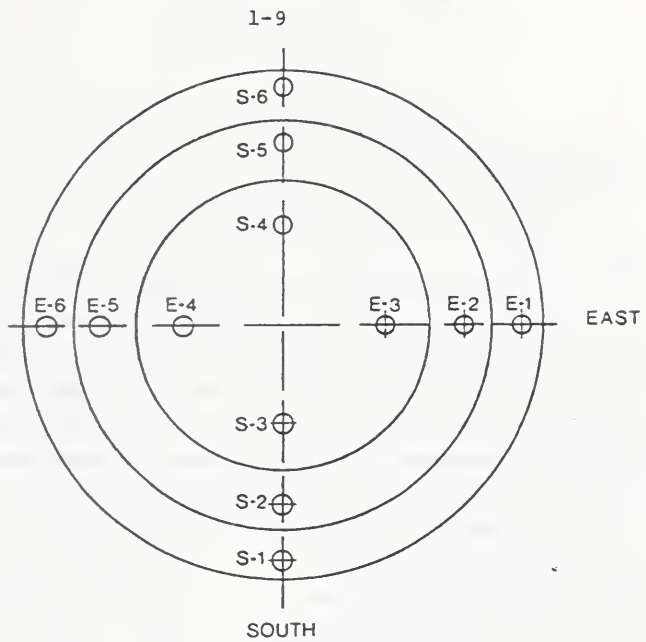
FIGURE 2:   Location of traverse points on circular and rectangular cross-sections divided into 12 equal areas.

APPENDICES TO METHOD 1

Appendix 1A - Site location with respect to flow disturbances

It is assumed that sampling will be representative (within stated limitations) at any site which is more than 4 diameters downstream and 1 diameter upstream from a flow disturbance, provided that the code procedure is followed. The basis for this assumption is that at such distances the flow should have a relatively uniform profile or be uniform enough so that with an increased number of sampling points, representative data can be obtained. Unfortunately, there are some exhausts where these geometrical requirements are not satisfied. In such cases, it may be possible to obtain representative data provided that the flow profile is of an acceptable configuration and the particle mass mean diameter is not too large. Acceptable sampling programs will be devised on a case by case basis in consultation with the Provincial Officer.

Appendix 1B - Sampling in non-circular, non-rectangular stack or duct cross-
sections

In the case of a stack or duct with an elliptical cross-section the following procedure is used to determine the sampling site and sampling points:

i)   Determine the location of the sampling site and the number of sampling points per traverse according to the method, using the major axis as the diameter; an equal number of sampling points are used for the major and minor axes.

ii)   For location of sampling points on the major axis, the following equation is used:

$$Y = \frac{A(2n - 1)}{N} \qquad \qquad \text{eq. 1(6)}$$

where Y = distance from centre of elliptical cross-section to sampling
point n

n = the number of a sampling point, the points being numbered from
the centre outwards

N = total number of sampling points per traverse

A = half the length of the major axis

iii)   For location of sampling points on the minor axis, the following equation is used:

$$X = \frac{B(2n - 1)}{N} \qquad \text{eq. 1(7)}$$

where X = distance from centre of elliptical cross-section to sampling point n

n = the number of a sampling point, the points being numbered from the centre outwards

N = total number of sampling points per traverse

B = half the length of the minor axis

Note: Equations 1(6) and 1(7) are used to calculate the location of pairs of sampling points equidistant from the centre.

Equivalent diameters of non-circular, non-rectangular and non-elliptical cross-section is obtained by calculating the ratio 4A/P, where A stands for area and P for perimeter.

Appendix 1C - Elimination of cyclonic or reverse flow

In some cases it may be practical to eliminate cyclonic or reverse flow in the stack or duct. This may be accomplished by altering the stack or duct by removal of internal obstructions, extension, addition of straightening vanes, alteration of inlet configuration, etc. If the problem cannot be overcome, reference should be made to the Air Resources Branch to discuss the matter.

Appendix 1D - Stack or duct diameter less than 0.3 m (1 ft) or greater than   5.0 m (16 ft)

Use of the usual sampling equipment in small diameter stacks or ducts presents obvious spatial difficulties. Altering the stack or duct by expanding its cross-sectional area may not be an adequate solution since the resulting flow velocity may be too low to be measured accurately. In all cases where the stack or

duct diameter is less than 0.3 m (1 ft), the Provincial Officer should be contacted to discuss the matter.

In the case of diameters larger than 5.0 m (16 ft) the Provincial Officer should be contacted in order to determine an acceptable number of sampling points. Extrapolation of Table 1 for large stacks might indicate an unnecessarily large number of sampling points in some cases.

Some stacks or ducts may be so large that it is impossible to traverse the entire diameter with a commercially available probe. It may be necessary then to use four ports, equally spaced about the stack or duct, in the plane of the cross-sectional area of the sampling site. It may also be necessary to construct a probe which would be long enough to perform a whole or a half traverse. In such cases the Provincial Officer should be contacted before any sampling procedure is finalized.

Bibliography

1. Environmental Protection Agency, Standards of Performance for New Stationary Sources, Federal Register, Part II, Vol. 42, No. 160, pp. 41754 to 41782, Aug. 18, 1977.

2. Environment Canada, Report EPS 1-AP-74-1, Standard Reference Methods for Source Testing: Measurement of Emissions of Particulates from Stationary Sources, February, 1974.

3. Ministry of the Environment, Province of Ontario, Source Testing Code, January, 1973.

4. Canadian Standards Association, CSA Standard Z223.1 - M1977, Method for the Determination of Particulate Mass Flows in Enclosed Gas Streams, October, 1977.

5. American Society for Testing and Materials, 1977. Annual Book of ASTM Standards, Part 26 Gaseous Fuels; Coal and Coke; Atmospheric Analysis 1977.

METHOD 2

DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE

METHOD 2

DETERMINATION OF STACK GAS VELOCITY
AND VOLUMETRIC FLOW RATE

1. PURPOSE

To determine the velocity profile, the average gas velocity and volumetric flow rate in a stack or duct. The method is based on the measurement of the velocity pressure heads and stack gas temperatures and takes into account the stack gas molecular weight, pressure and the configuration of the stack or duct.

2. LIMITATIONS

The basic method is not applicable in the following cases:

i)   cyclonic or reverse flow (see Method 1)

ii)   gas velocity pressure too small to be accurately measured with an inclined manometer or device of equivalent sensitivity (see below)

iii)   fluctuating velocity pressure readings (see below)

Where any of the above situations occur, reference should be made to the appendices.

3. APPARATUS

i)   Pitot tube - S-type (Stausscheibe or reverse type); alternatively, a standard pitot tube may be used where particulate or condensate plugging of the static and impact pressure holes will not occur; description of both types of pitot tubes may be found in Appendix 2A.

ii)   Differential pressure gauge - Inclined manometer or device of equivalent sensitivity, readable to the nearest 0.13 mm H_2O (0.005 in. H_2O) for $\triangle P$ values between 0.13 and 25 mm H_2O (0.005 in. H_2O to 1.0 in. H_2O) and readable to the nearest 1.3 mm H_2O (0.05 in. H_2O) for $\triangle P$ values greater than 25 mm H_2O (1.0 in. H_2O); a more sensitive gauge is required if a $\triangle P$ reading covers less than 5 inital smallest scale divisions; see Appendix 2C regarding more sensitive gauges.

iii)   Temperature sensor - Thermocouple or other calibrated device capable of measuring stack gas temperature to within 1.5 percent of the minimum gas

temperature; temperature sensor must be checked according to the procedure of Appendix 2E.

iv)   Probe - The combination of a calibrated pitot tube and temperature sensor rigidly fixed to a sampling probe, facilitating simultaneous measurement of temperature and velocity pressure head at each point during sampling. The configuration of this combination is detailed in Appendix 2A.

NOTE: The sampling probe can be omitted when the stack gas velocities only are measured; however, this combination of temperature sensor fixed to the pitot tube must be calibrated separately.

v)   Stack gas pressure sensor - The static tap of a standard pitot tube or one leg of an S-type pitot tube, with the face opening planes positioned parallel to the gas flow, connected to a manometer capable of measuring stack pressure to within 2.5 mm Hg (0.1 in. Hg) or equivalent devices.

vi)   Barometer - Capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg); alternatively, the daily atmospheric pressure as provided by Environment Canada may be used with an altitude adjustment being made for the elevation of the sampling site at a rate of 2.5 mm Hg (0.1 in. Hg) per 30 meters (100 ft) of elevation increase.

vii)   Gas molecular weight and moisture content - Methods 3 and 4 are used to determine the molecular weight and the moisture content of the stack gas.

4.   PROCEDURE

i)   The pitot tube must be calibrated in accordance with the procedure of Appendix 2A. It must be calibrated before use, in exactly the same configuration as it will be used in the stack or duct, i.e., alone or as part of a probe assembly (nozzle, thermocouple, sheathing), with all the nozzles that will be used in sampling. Before each test, the pitot must be examined to determine if it has incurred any damage, especially to its leading edge. If damaged, it must either be repaired or replaced, and in either case, recalibrated. Also, if the pitot tube has shifted in position relative to the other components of the probe assembly since the last calibration, the pitot must be recalibrated before use or repositioned exactly.

ii)   If a differential pressure gauge other than a manometer is used, it must be calibrated before and after each test series, in accordance with Appendix 2B.

iii)   If a manometer is used, it must be levelled and zeroed before measurements and the level periodically checked during the measurement. All data are to be recorded according to the format demonstrated in Figure 3.

iv)   Determine the stack gas static pressure by connecting one leg of the manometer to the static tap of a standard pitot tube or to one leg of an S-type pitot tube with the face opening planes positioned parallel to the gas flow. This reading may be positive or negative depending on the conditions in the stack or duct. Determine the atmospheric pressure using the barometer. The static pressure reading, if necessary, is converted to the units of the atmospheric pressure reading and added to that pressure to give the absolute stack gas pressure, in accordance with equation 2(1) or 2(4).

v)   Determine the stack gas molecular weight and moisture content in accordance with Methods 3 and 4.

vi)   The velocity pressure, ΔP, and temperature are measured at each sampling point. The pitot is held at each point for at least one minute, while a reading is determined from the pressure differential gauge. The velocity pressure tap of the standard pitot or the face opening planes of the S-type pitot are maintained perpendicular to the longitudinal axis of the stack or duct. If a ΔP reading is less than 5 smallest scale divisions, a more sensitive gauge must be used at that point. (See Appendix 2C).

vii)   Figure 3 indicates that 3 readings are required for the ΔP data. The middle column is for the ΔP which is observed or assumed to be the average ΔP at that point. If the ΔP reading is fluctuating, an average ΔP must be estimated for the purpose of calculation. The other two ΔP readings are the lowest and highest values of ΔP observed during the particular time period (e.g., 2.5 minutes if done during sampling or at least one minute if done on a velocity traverse). If the absolute difference between the high or the low value and the estimated average is greater than 20% of the estimated average, the data are unacceptable and reference should be made to Appendix 2D. The high and low values do not have to be recorded if the velocity is stable.

viii)   Calculate the stack gas velocity at each sampling point according to equation 2(2) or 2(5) and then calculate the average stack gas velocity and stack gas volumetric flow rate using equation 2(3) and 2(6).

FIGURE 3. FIELD SAMPLING REPORT
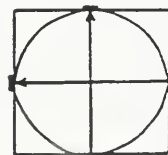
Plant*
Location*
Date*
Operators*
Run. No.
Pitot Coefficient* 0.762
Dry Gas Meter Correction Factor

Schematic of stack cross-section; indicating compass direction, orientation of traverses and upstream flow disturbances

Ambient Temperature (°C) 29*
Atmospheric Pressure, P bar (in. Hg) 29.73*
Assumed Moisture (%) 12.4*
Static pressure, P static (in. H_2O) - 0.4*
Stack Diameter (ft) 3.58*
Nozzle Diameter (in.)
Probe Length (ft)
Probe Liner
Stack Gas Molecular Weight (lb/lb mol)

Traverse Number and Direction -

Sampling Point Number	Sampling Time (Min.)	Stack Temp. T_s (°F)	Velocity Head ΔP_s (in.H_2O) Low	Avg.	High	Orifice Pressure Drop Δh (in.H_2O)	Gas Sample Volume, Vm. (cu.ft.)	Dry Gas Meter Temperature Inlet T_M in (°F)	Outlet T_M out (°F)	Sample Box Temp. (°F)	Impinger Outlet Temp. (°F)	Vaccum (in.Hg.)
1	0	220		0.67								
	3	220		0.67								
2	6	250		1.34								
	9	250		1.55								
3	12	250		1.55								
	15	250		1.65								
4	18	250		1.55								
	21	250		1.55								
5	24	250		1.55								
	27	250		1.03								
6	30	250		1.03								
	33	255		1.03								
7	36	255		1.03								
	39	255		1.03								
8	42	250		1.03								
	45	250		1.03								
	48	250		1.03								

* Information required for Method 2

5. EQUATIONS

SI Units

$$P_s = P_{bar} + 0.098 \, P_{static} \qquad \text{eq. 2(1)}$$

where P_s =   absolute stack gas pressure (kPa)

             P_{bar} =   atmospheric pressure (kPa)

             P_{static} =   stack gas static pressure (cm H_2O)

             0.098   =   factor to convert cm H_2O to kPa

$$U_s = 128.6 \, C_p \sqrt{\frac{\Delta P \, T_s}{M_s P_s}} \qquad \text{eq. 2(2)}$$

where U_s =   stack gas velocity (at a point) (m/sec)

             C_p =   pitot tube coefficient

             T_s =   absolute stack gas temperature ($^{\circ}$K)

             ΔP =   stack gas velocity head (kPa)

             M_s =   stack gas molecular weight - wet basis (kg/kmol)

             P_s =   absolute stack gas pressure (kPa)

$$Q_s = 3600 \, U_{s(avg)} A_s (1 - B_{wo}) \frac{T_{ref} P_s}{T_{s(avg)} P_{ref}} \qquad \text{eq. 2(3)}$$

where Q_s =   stack gas volumetric flow rate - dry basis at reference conditions (m³/hr)

             $U_{s(avg)}$ =   average stack gas velocity (m/sec) (average of U_s's determined at each point)

             A_s =   cross-sectional area of stack or duct (m²)

             B_{wo} =   proportion of water in stack gas

             T_{ref} = 298°K

             $T_{s(avg)}$ =   average stack gas temperature ($^{\circ}$K) (average of T_s's determined at each point)

             P_s =   absolute stack gas pressure (kPa)

             P_{ref} =   101.325 kPa

<u>British Units</u>

$$P_s = P_{bar} + \frac{P_{static}}{13.6}$$ eq. 2(4)

where P_s = absolute stack gas pressure (in. Hg)
P_{bar} = atmospheric pressure (in. Hg)
P_{static} = stack gas static pressure (in. H_2O)

$$U_s = 85.35 \, C_p \sqrt{\frac{\Delta P \, T_s}{M_s P_s}}$$ eq. 2(5)

where U_s = stack gas velocity (at a point) (ft/sec)
C_p = pitot tube coefficient
T_s = absolute stack gas temperature (^oR)
ΔP = stack gas velocity head (in. H_2O)
M_s = stack gas molecular weight - wet basis (lb/lb-mol)
P_s = absolute stack gas pressure (in. Hg)

$$Q_s = 3600 \, U_{s(avg)} A_s (1 - B_{wo}) \, \frac{T_{ref} P_s}{T_{s(avg)} P_{ref}}$$ eq. 2(6)

where Q_s = stack gas volumetric flow rate - dry basis at reference conditions (ft^3/hr)
$U_{s(avg)}$ = average stack gas velocity (ft/sec) (average of U_s's determined at each point)
A_s = cross-sectional area of stack or duct (ft^2)
B_{wo} = proportion of water in stack gas
T_{ref} = 537^oR
$T_{s(avg)}$ = average stack gas temperature (^oR) (average of T's determined at each point)
P_s = absolute stack gas pressure (in. Hg)
P_{ref} = 29.92 in. Hg

6. DISCUSSION OF METHOD 2

Purpose

This method is applied in all cases of representative measurement of enclosed gas flows. Given the gas composition as determined by Methods 3 and 4, with this method the gas velocity is determined at each point of a cross-sectional area as defined by Method 1. The average velocity of the stack gas and an overall stack gas volumetric flow rate are then calculated.

Limitations

Method 2 is not applicable, if cyclonic or reverse flow is present at the sampling location. The method requires that the flow at the sampling point be reasonably parallel to the longitudinal axis of the stack or duct and in the general direction of the gas stream. If cyclonic flow is suspected, its presence is confirmed by the procedure outlined in Method 1.

This method is also not applicable in situations where the gas velocity is so low that the differential pressure gauge is unable to accurately measure the velocity pressure head; the limit is 5 smallest scale divisions. For most manometers on stack sampling units, this limit is 1.3 mm H_2O (0.05 in. H_2O), which corresponds to about 3.6 m/sec (12 ft/sec) for an ambient air stream at ambient temperature. Reference should be made to Appendix 2C concerning more sensitive gauges.

A further limitation to the applicability of Method 2 occurs in cases where the stack gas velocity fluctuates significantly, i.e., ΔP readings at a point vary more than $\pm 20\%$ of the estimated average ΔP reading. A 20% error with respect to ΔP represents approximately a 10% error in the velocity calculation. At lower velocities, the inaccuracy of a fluctuating reading is compounded by the greater relative error associated with reading the pressure gauge at the low end of the scale. If severe fluctuations are encountered, reference should be made to Appendix 2D. It is noted that this method is not limited with respect to sampling site selection criteria in relation to upstream and downstream flow disturbances outlined in Method 1; i.e., this method may be used at any point in a flowing gas stream to determine the velocity at that point. However, at points closer to a disturbance, there is a greater likelihood of fluctuating velocities and thus more inaccuracy in the ΔP readings. Thus the same geometrical limitations outlined in Method 1 may be applicable when determining whether or not a given sampling site is satisfactory for representative flow measurements.

7.   SAMPLE CALCULATIONS

In order to illustrate the calculations performed as part of this method, data from a velocity traverse are given in Figure 3. Normally, two velocity traverses would be performed and the point velocities from both would be averaged. Here only one traverse is used as an example. All the information required for the purposes of Method 2 is provided. Molecular weight has been obtained according to procedures outlined in Methods 3 and 4. Sampling times are not necessary for Method 2 but have been added to indicate that two readings were taken at each point. The columns for the lowest and highest Δ P's observed at the points have not been filled in as it is assumed for this example that the gas velocity is stable.

Given the data in Figure 3, the following calculations are made:

$$P_s = P_{bar} + \frac{P_{static}}{13.6} \qquad\qquad \text{eq. 2(4)}$$

$$= 29.73 + \left(\frac{-0.4}{13.6}\right)$$

$$= 29.70 \text{ in. Hg}$$

U_s(at first point, first reading)

$$= 85.35\, C_p \sqrt{\frac{\Delta P\, T_s}{M_s P_s}} \qquad\qquad \text{eq. 2(5)}$$

$$= 85.35(0.762) \sqrt{\frac{0.67(680)}{27.65(29.7)}}$$

$$= 48.4 \text{ ft/sec}$$

TABLE 4 provides the velocities calculated for the entire traverse.

$$A_s = \frac{\pi d^2}{4}$$

$$= \frac{3.14(3.58)^2}{4}$$

$$= 10.07 \text{ ft.}^2$$

where d = stack inside diameter

$$Q_s = 3600 \, U_{s(avg)} \, A_s \, (1-B_{wo}) \frac{T_{ref}P_s}{T_{s(avg)}P_{ref}}$$

$$= 3600 \, (64.8) \, (10.07) \, (0.876) \frac{(538)(29.7)}{(707.2)(29.92)}$$

$$= 1.55 \times 10^6 \text{ ft}^3/\text{hr}$$

where moisture content, B_{wo} = 0.124

$T_{s(avg)}$ = 707.2 $^\circ$R

TABLE 4			
Calculated point velocities and average velocity			
Traverse Point	Velocity (ft/sec)	Traverse Point	Velocity (ft/sec)
1	48.4 48.4	5	61.4 61.4
2	75.3 69.9	6	61.6 61.6
3	75.3 77.7	7	61.6 61.4
4	75.3 75.3	8	61.4 61.4

The average velocity for the traverse, U_s(avg) = 64.8 ft/sec

APPENDICES TO METHOD 2

Appendix 2A - Construction and calibration of pitot tubes

For the purposes of Method 2 and any other method where a pitot tube is required, the pitot tube must be properly calibrated. That is, the pitot must be calibrated exactly as it will be used, i.e., if used as part of a probe assembly (nozzle, temperature sensor and sheathing), the pitot must be similarly fixed in relation to the other components of the assembly for both calibration and usage. Furthermore, if there is any noticeable, but very minor damage to the pitot openings or if there is noticeable but unremovable particulate build-up, either of which has occurred since the last calibration, the pitot must be recalibrated before use.

In the case of a compliance test, it is mandatory and in the other cases it is suggested, that, if a pitot is used, the most recent calibration data and results be included in any report submitted to the Ministry. These data should be dated and signed by the person(s) performing the calibration.

A standard pitot tube generally has a design similar to that shown in Figure 4 and a coefficient of 0.99 ± 0.01. Prior to use, an inspection should be performed to confirm that it has not been damaged in any manner.
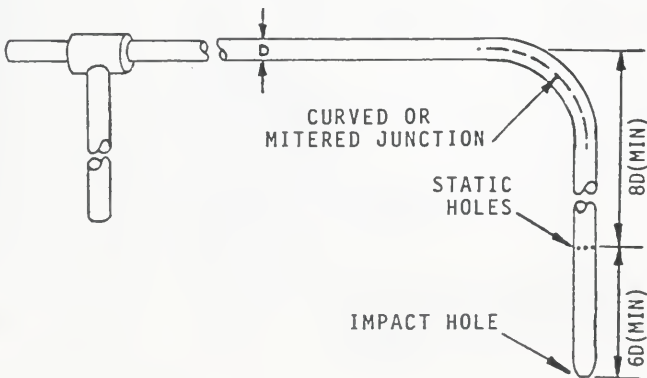
FIGURE 4. Standard pitot tube

A S-type pitot is constructed according to the design shown in Figure 5. All S-type pitots must be calibrated. Preferably, the S-type pitot will have face opening planes perpendicular to the tube transverse axis and parallel to the tube longitudinal axis, both legs of equal length and centrelines coincident when viewed from the sides. Generally $P_A = P_B$ and $1.05\,D_t < P < 1.50\,D_t$ and D_t is between 0.48 and 0.95 cm (3/16 to 3/8 in.). It is permissible to use S-type pitot which have minor deviations from the above criteria, provided the deviations existed when the tube was calibrated. If, in use, such deviations or damage to the S-type occurs, the pitot must be repaired, where practical, and recalibrated.

FIGURE 5. S-type pitot tube a) end view, b) top view,
c) side view

Generally, the probe assembly, including the pitot, will be constructed according to the designs shown in the following figures. Both goose-neck (button-hook) type and 90° 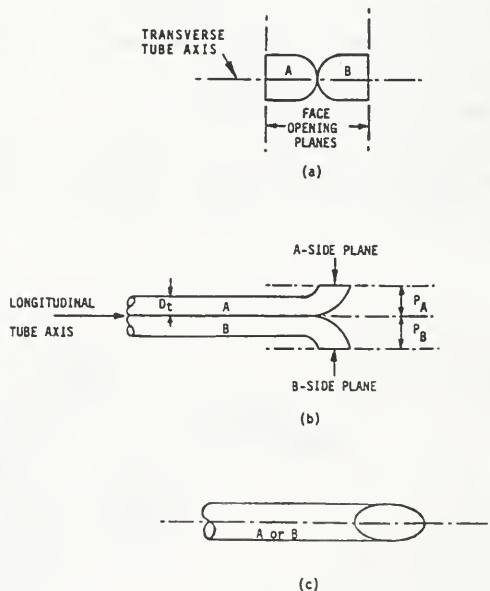bend nozzles may be used except in stacks or ducts with heavy dust loading where only goose-neck nozzles may have to be used. Figures 6 and 7 indicate recommended spatial requirements so that aerodynamic interference among components of the assembly is minimized. However, these distances may only be slightly exceeded since the function of the probe assembly is to measure stack parameters as close as possible to the point where the sample is drawn into the probe.

The temperature sensor is attached so that the sensor tip does not touch any metal. The tip of the nozzle must extend least 2 nozzle diameters below the tip of the upstream leg of the S-type pitot tube.

The S-type pitot tube on a probe assembly must be calibrated with each nozzle that will be used in sampling.

A. BOTTOM VIEW SHOWING RECOMMENDED PITOT-NOZZLE SEPERATION

B. SIDE VIEW: TO PREVENT PITOT TUBE FROM INTERFERING WITH GAS FLOW STREAMLINES APPROACHING THE NOZZLE. THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR ABOVE THE NOZZLE ENTRY PLANE.

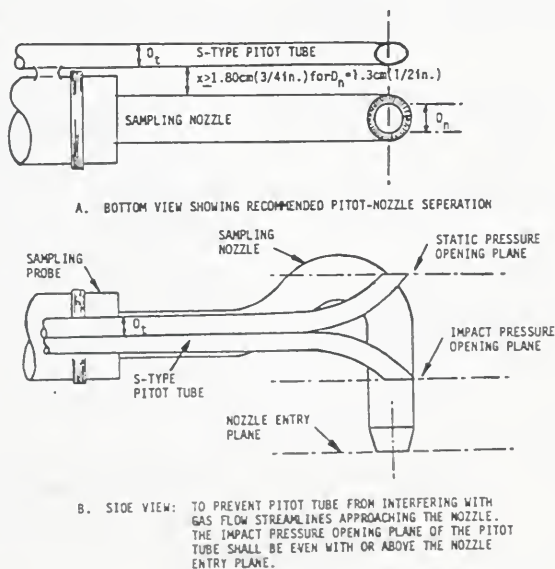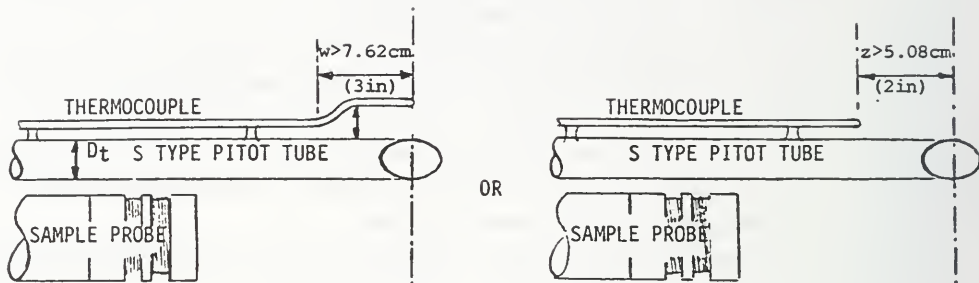FIGURE 6.   Pitot tube-sampling nozzle configuration; buttonhook-type nozzle; centers of nozzle and pitot opening aligned; D_t between 0.48 and 0.95 cm. (3/16 and 3/8 in.).

PROPER THERMOCOUPLE PLACEMENT TO PREVENT INTERFERENCE;
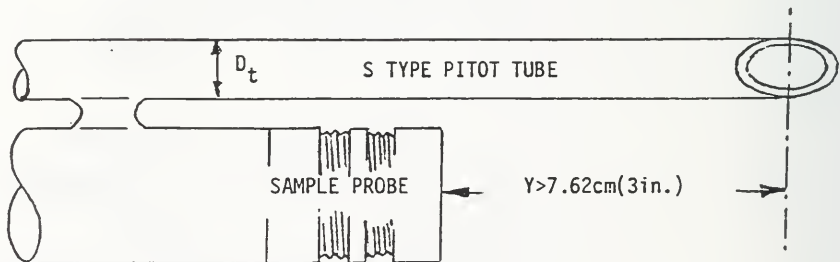D_t BETWEEN 0.48 and 0.95cm (3/16 and 3/8 in.)

FIGURE 7.   Minimum pitot-sample probe-thermocouple
separation needed to prevent interference;
D_t between 0.48 cm and 0.95 cm (3/16 and 3/8
in.)

Calibration Apparatus -

i)   Wind Tunnel - Flowing gas stream confined in a duct of constant cross-sectional area, either circular or rectangular; minimum cross-sectional area must be 9000 cm^2 (1400 in.^{2}); cross-sectional area must be constant for 10 diameters (equivalent diameters) downstream and 2 upstream from a flow disturbance; deviation from the above is permissible if it is demonstrated that the flow is stable and parallel to the longitudinal axis of the duct; the gas stream is moved by a device capable of generating at least five different stream velocities; these velocities should reasonably cover the range of velocities anticipated in the field.

ii)   Reference Pitot Tube - A pitot of known coefficient, either standard or S-type.

iii)   S-type - (Stausscheibe or reverse type) Pitot Tube (with probe assembly, if applicable).

iv)   Differential Pressure Gauge - Inclined manometer or device of equivalent sensitivity, readable to the nearest 0.13 mm H_2O (0.005 in. H_2O) for ΔP values between 1.3 mm H_2O and 25 mm H_2O (0.05 to 1.0 in. H_2O) and readable to the nearest 1.3 mm H_2O (0.05 in. H_2O) for ΔP values above 25 mm H_2O (1.0 in. H_2O).

Calibration Procedure -

        Pitot calibration is performed by comparing, mathematically, the ΔP readings taken from a reference pitot and those from the pitot of unknown coefficient, at the same wind tunnel gas velocity.

i)   Position the reference pitot tube at or near the centre of the wind tunnel and position the S-type pitot in the same cross-sectional plane or a minimum distance of 2 tunnel diameters downstream of the reference. In either case it must be experimentally determined that the velocity of the gas stream is the same at the reference point and at the S-type point, i.e., by using the reference pitot, the same ΔP reading is obtained for each test velocity at the two points. If the S-type is positioned in the same plane as the reference, the pitots must be placed a minimum of 7.5 cm (3 in.) apart so as to avoid any interference effects. Align the pitots so that they are facing directly into the flowing gas stream. Ensure that the pitot ports are completely sealed.

ii)   Attach manometers to each of the pitot tubes and ensure that they are filled with clean fluid of the correct density. Inspect and leak check all pitot lines. Level and zero the manometers.

iii)   Start the wind tunnel flow and record the velocity pressure heads from the reference pitot, ΔP_{std} and the S-type pitot ΔP_s, at at least 5 different velocities, these velocities covering the range anticipate when the S-type is used in the field.

(a)   (b)
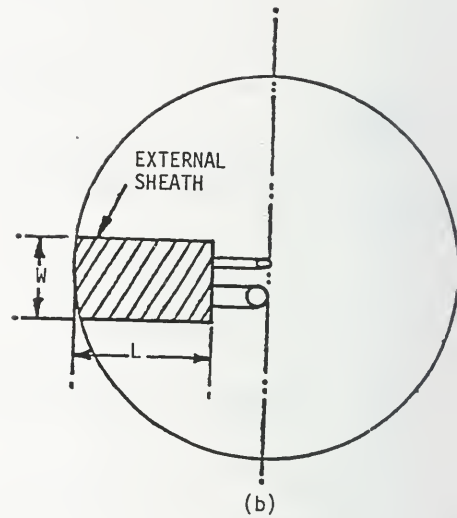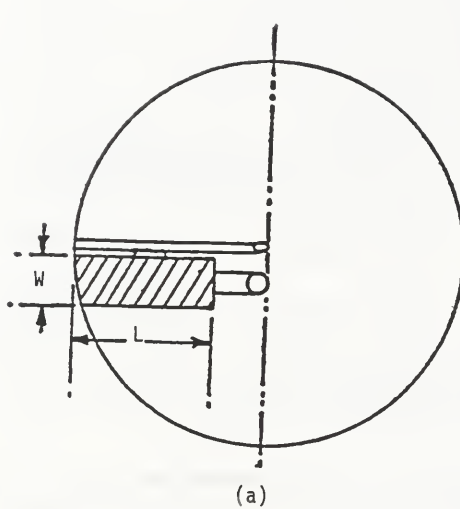
$$\text{Percentage Estimated Blockage} = \frac{LW}{\text{Duct Area}} \times 100 \qquad \text{eq. 2(7)}$$

FIGURE 8. Projected area models for typical probe assemblies.

iv)   The point where the S-type pitot is positioned must be at or near the centre of the wind tunnel. However, insertion of a probe assembly into a small wind tunnel may cause significant cross-sectional area blockage and yield incorrect coefficient values. Therefore, to minimize the blockage effect, the calibration point may be a few inches off-centre, if necessary. The actual blockage effect will be insignificant when the theoretical blockage, as determined by a projected area model of the probe, is 2% or less of the duct (Figure 8, eq. 2(7)). The probe assembly must be moved to comply with the criterion or a larger tunnel must be used.

v)   Data are recorded as in Figure 9.

vi)   The S-type pitot coefficient, Cp_s, is calculated using equation 2(8):

$$Cp_s = Cp_{std}\sqrt{\frac{\Delta P_{std}}{\Delta P_s}} \qquad \qquad \text{eq. 2(8)}$$

$$
\begin{aligned}
Cp_{std} \quad &= \quad \text{coefficient of standard pitot} \\
&= \quad 0.99 \pm 0.01 \\
Cp_s \quad &= \quad \text{coefficient of S-type pitot}
\end{aligned}
$$

and plotting graphically $\sqrt{\Delta P_{std}}$ versus $\sqrt{\Delta P_s}$ obtained at each point. The Cartesian points are then joined by the best fitting curve. If this is not straight throughout the full test range, a best fitting straight line must be drawn through the points corresponding to the expected stack velocities and the slope of that line used as the Cp_s for the particular test. Calibration velocities may be calculated according to Eq. 2(2) using the ΔP_{std} and Cp_{std}. Moisture content and the temperature of air in the wind tunnel can be measured by the use of wet and dry bulb thermometry and psychometric charts.

Date: Operators: Location: S-type Identification: Probe Nozzle Size:		Ambient Temperature: Barometric Pressure: Relative Humidity: Wind Tunnel Description:	
Test Velocity Number	Wind tunnel static pressure (in. H_2O)	ΔP_{std} (in. H_2O)	ΔP_s (in. H_2O)
1 2 3 4 5 6 . . .			

FIGURE 9. Pitot calibration data

Appendix 2B - Calibration of differential pressure gauges other than manometers

It is necessary to calibrate other differential pressure gauges before each test series. This is done by comparing ΔP readings obtained with the gauge and an inclined manometer at at least 3 different flow velocities which approximate the ΔP's found in the stack or duct. The readings must agree to within 5% at each point for the gauge to be acceptable (See Eq. 2(9)). Calibration results are reported as shown in Figure 10.

$$\text{Percent difference} = \frac{\Delta P_{gauge} - \Delta P_{manometer}}{\Delta P_{manometer}} \times 100 \qquad \text{eq. 2(9)}$$

Test Number	$\Delta P_{manometer}$ (in.H$_2$O)	ΔP_{gauge} (in.H$_2$O)	Percent Difference
1			
2			
3			
.			
.			
.			

FIGURE 10. Pressure differential gauge calibration data

Appendix 2C - Substitutes for inclined manometers in the case of low stack gas velocities

As stated in subsection (ii) of section 3, Method 2, Apparatus, if a ΔP reading is found to be less than 5 smallest scale divisions on the gauge being used, a more sensitive device must be employed. Such devices include: vane anemometer (low temperature source); Hastings-Raydist "Stack Gas Velocity Meter"; Dwyer Instruments, Inc., "Microtector"*; Fluidynamic Device Limited "Fluidic Velocity Sensor"; etc.

Appendix 2D - Fluctuating velocity pressure readings

As stated in subsection (vii) of section 4 of this method procedure, if a ΔP reading fluctuates more than ±20% of the assumed average value at a point, the data gathered at the point are unacceptable. Fluctuation of gas velocity generally does not arise due to stack or duct configuration but rather variations in the process or upstream machinery. If the operation of the process or machinery cannot be stabilized, it may be possible to dampen the fluctuations in velocity by

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* Trade Mark

extending the stack or duct or providing a stack gas expansion chamber before the differential pressure gauge. If this problem is encountered, the Provincial Officer should be contacted to discuss possible solutions.

Appendix 2E - Calibration and check of temperature sensor

The temperature sensor must be calibrated according to accepted routine procedures and the calibration values checked before each test series. This is done by comparing sensor readings to several known temperatures covering the range expected in the field. The apparatus used for this purpose are an ice bath, boiling water and a heated oil bath with a liquid-filled thermometer. If the sensor readings do not compare within 1.5% of the known absolute temperatures, the sensor must be replaced.

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METHOD 3

DETERMINATION OF MOLECULAR WEIGHT OF DRY STACK GAS

METHOD 3
DETERMINATION OF MOLECULAR WEIGHT
OF DRY STACK GAS

1. **PURPOSE**

To determine the concentrations of O_2, CO_2, CO and N_2 and the dry stack gas molecular weight.

2. **LIMITATIONS**

This method is not applicable per se in the following case: gas streams with significant concentrations of gases other than O_2, CO_2, CO, N_2, Ar and H_2O (e.g., SO_2). Where this situation occurs, reference should be made to the appendices.

3. **APPARATUS**

(a) Grab Sampling (See Figure 11)

i) Probe - stainless steel or borosilicate glass with in-stack (e.g., glass wool plug) or out-stack particulate filter; other materials inert to the sampling gases are acceptable.

ii) Pump - one-way squeeze bulb or equivalent device.

iii) Moisture Removing Device - (optional, if moisture content of stack gas is not greater than that of ambient air) - a device to remove water from gas stream without removing the gaseous components.

iv) Gas analyzer - Orsat (See Appendix 3A), gas chromatograph or other device(s) provided that gas component percentage is measurable to at least 0.2% and is determined on a dry basis.

(b) Integrated Sampling (See Figure 12)

i) Probe - As above

ii) Condenser - As above

iii) Pump - leak free, diaphragm pump or equivalent; surge tank between pump and rotameter to dampen diaphragm pulsation effect.

iv) Valve - needle valve to adjust sample gas flow rate.

v) Flow rate meter - rotameter or equivalent device capable of measuring flow to within ±2% of the selected flow rate.

vi) Flexible bag - leak free, inert, plastic (e.g., Tedlar*, Mylar*, Teflon*) or plastic coated aluminum (e.g., aluminized Mylar*) or equivalent; capacity consistent with flow rate and sampling time (suggested: at least 30 litres (1 ft^3)).

vii) Gas Analyzer - As above

4. PROCEDURE

(a) Grab Sampling

If the stack gas flow is non-stratified and its composition remains uniform, the following procedure is used to determine the dry molecular weight.

i) Assemble the grab sampling train as shown in Figure 11; a pump may be necessary if the source is under a vacuum. Ensure that all connections ahead of the analyzer are secure and leak-free.

ii) Assemble the analyzer, calibrate, and leak-check it according to the manufacturer's instructions or accepted standard procedure.

iii) Position the probe at the centre of the stack or duct when diameter is smaller than 2.0 m (6.6 ft) or at a point no closer than 1.0 m (3.3 ft) to the walls of larger stacks or ducts. Purge the sampling system and then draw a sample into the analyzer and immediately analyze for the percentages of CO_2, CO, O_2 and N_2. Calculate the dry molecular weight according to equations 3(1) to 3(3). Repeat the sampling and analysis two more times. Individual values should not deviate from their mean by more than 0.3 kg/kmol (lb/lb-mole). If they do, repeat the procedure three more times and select three determinations which satisfy the above criterion of deviation. Report the mean value to the nearest 0.1 kg/kmol (lb/lb-mole). (Note: the concentrations of the individual components are used only to determine the molecular weight. They are not necessarily representative of the true values as a stricter criterion of precision should be used for individual component analysis.)

iv) Results for stack gas composition determination are recorded as shown in Figure 13.

(b) Integrated Sampling

If the stack gas flow is non-stratified but its composition varies with time or if the precision criterion for grab sampling cannot be met, the following procedure is used to determine the dry molecular weight:

i) The sample bag must be leak-checked prior to use, according to the following procedure: connect the bag to a manometer and pressurize it to 5 to 10 cm H_2O (2 to 4 in.); allow to stand for 10 minutes; any displacement of the manometer indicates a leak. Alternatively, allow the pressurized bag to stand overnight; a deflated bag indicates a leak.

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*Trade Mark - E.L. DuPont De Nemours & Co.

ii)   Assemble the integrated sampling train as shown in Figure 12.   The configuration of the train is optional provided that a dry sample can be drawn into an unreactive sample bag at a constant rate.   Ensure that all connections are secure and leak-free.

iii)   Assemble the analyzer, calibrate and leak-check it according to the manufacturer's instructions or accepted standard procedure.

iv)   Position the probe at the centre of the stack or duct when diameter is smaller than 2 m (6.6 ft) or at a point no closer than 1.0 m (3.3 ft) to the walls of larger stacks or ducts.   Continuously draw a sample into the bag, at a constant rate, throughout the stack gas velocity traverse or the particulate test.   The sampling rate is fixed to provide a full sample bag at the completion of the test. Recommended sample volume is about 30 litres (1 ft^3).

v)   Analyze the integrated sample within 8 hours of collection and calculate the dry molecular weight according to equations 3(1) and 3(3).   Repeat the analysis until the molecular weights of any three determinations differ from their mean by no more than 0.3 kg/kmol (lb/lb-mole) and report the mean value to the nearest 0.1 kg/kmol (lb/lb-mole).

(c)   Stratified Gas Flow

Gas stratification in the stack or duct may be present where there is an ambient air intake close to the sampling site, mixing of exhausts from different processes, or possibly in horizontal ducts carrying a mixture of gases, one or more of which is relatively heavier than the others, etc. Where stratification is known or suspected to exist, the following procedure is used to determine the dry molecular weight:

i)   Choose a traverse such that a gas concentration profile across it would reveal any stratification.   For example, the traverse should be parallel to the centre line down through the normal at the point of entry of the inlet gases into the duct or stack.   In the case of horizontal inlet bends into the duct or stack, the traverse is usually horizontal, while in the case of vertical inlet bends, the traverse is usually vertical.

ii)   In the case of stacks or ducts with diameters less than 1.0 m (3.3 ft), select 4 equally spaced points along the traverse; in the case of stacks or ducts having larger diameters, select 6 equally spaced points along the traverse.

iii)   Perform at least 3 molecular weight determinations according to the grab sampling techniques at each point.   Average the results at each point and
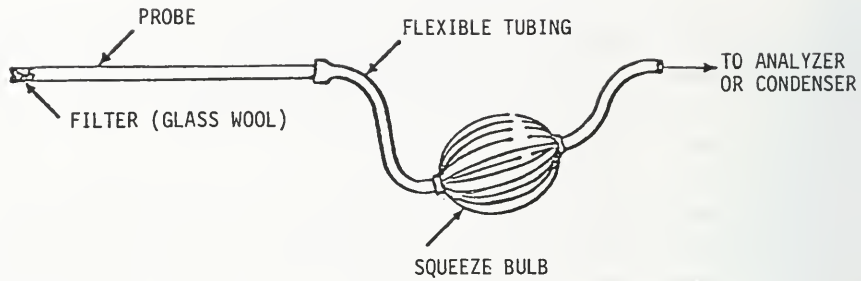
Figure 11. Grab sampling train.
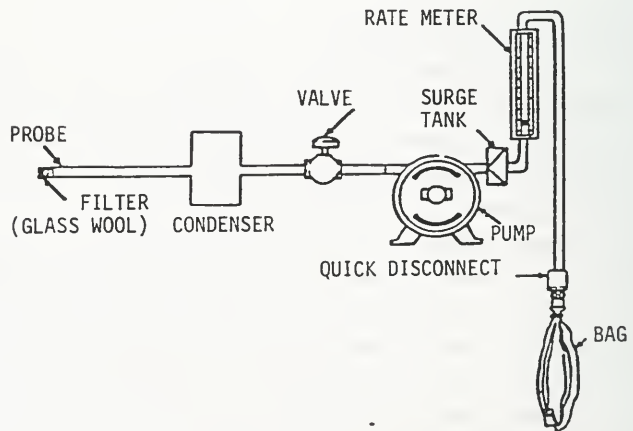
Figure 12. Integrated gas sampling train.

FIGURE 13. GAS COMPOSITION DATA

Date:
Operators:
Location:
Method of Sampling (grab or integrated):
Type of Analyzer:

Test Number	Replicate Analysis Number	%CO₂	%CO	%O₂	%N₂	%Ar	Molecular Wt. (Kg/Kmol) (lb/lb-mole)	Difference From Mean Molecular Wt.
Particulate 1	1 2 3 · · ·							
	Mean Molecular Wt. - _____ (Indicate the Averaged Replicates)							
2	1 2 3 · · ·							
	Mean Molecular Wt.							

determine the value to the nearest 0.1 kg/kmol (lb/lb-mole). Then average these values to determine the overall mean value. If the average values at each of the points are within ± 5% of the overall mean value, then the molecular weight may be determined by the integrated sampling technique. If one or more of the point values is not within ± 5% of the overall mean value, significant stratification is indicated and a specified technique will be required for molecular weight determination. See Appendix 3C.

5.   EQUATIONS

$$\%(N_2 + Ar) = 100 - (\%CO_2 + \%O_2 + \%CO) \qquad \text{eq. 3(1)}$$

$$\%Ar = .0119\ (\%N_2) \qquad \text{eq. 3(2)}$$

where % = % by volume
    Ar = argon (M.W. = 40)
    N_2 = nitrogen (M.W. = 28)
    CO_2 = carbon dioxide (M.W. = 44)
    CO = carbon monoxide (M.W. = 28)
    O_2 = oxygen (M.W. = 32)

Note: Argon is included in the calculations only if the main source of nitrogen is air.

$$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.40(\%Ar) + 0.28(\%N_2 + \%CO) \qquad \text{eq. 3(3)}$$

where M_d = molecular weight (dry basis) (kg/kmol or lb/lb-mole)

6.   DISCUSSION OF METHOD 3

Purpose

    This method is applied in all cases where it is necessary to determine the stack gas composition with respect to O_2, CO_2, CO, and N_2. Stack gas composition data are used to calculate the stack gas molecular weight and this value is ultimately used to calculate the stack gas flow rate.

Limitations

The presence of significant concentrations of gases other than O_2, CO_2, CO, NO_2 and Ar (ambient concentration) may interfere with the accurate operation of this method. These gases may interfere with the action of the analyzer or they may cause a dilution of the sample which is unaccounted for.

The Orsat analyzer is susceptible to both types of interferences. If the source contains an acid gas (e.g., SO_2, HCl), the determination of the CO_2 concentration will be erroneous since the acid gas is absorbed in the KOH solution along with the CO_2 (See Appendix 3B). Also, the presence of a gas which is unreactive with the Orsat absorbing solutions may affect the results since it will be included as part of the N_2 fraction.

Other types of analyzers are also susceptible to interference. This may include co-absorption in spectral absorption devices, quenching effects, etc. The specific analyzer must be examined with respect to the effects of the various stack gas components on its operation.

Apparatus

The configurations of the grab sampling and integrated sampling apparatus should resemble Figures 11 and 12. However, the use of other devices is permitted, provided the overall function of the apparatus is maintained, i.e., a representative sample of clean stack gas is transferred, without chemical change, from the source to the analyzer.

7.   SAMPLE CALCULATIONS

Shown below in Table 5 are sample stack gas composition data taken by the grab sampling method during a velocity traverse.

TABLE 5							
Replicate Analysis Number	%CO_2	%O_2	%CO	%N_2	%Ar	Molecular Wt. (Kg./Kmol.)	Difference From Mean Molecular Wt.
1	8.0	0.5	5.1	85.4	1.0	29.60	0
2	8.1	0.4	4.9	85.6	1.0	29.61	.01
3	7.9	0.5	5.0	85.6	1.0	29.58	.02
4	8.1	0.5	5.1	85.3	1.0	29.62	-
5	8.4	0.2	5.2	85.2	1.0	29.67	-
Mean Molecular Wt.						29.60	

In the above example, the mean molecular weight was calculated from replicate analyses 1, 2 and 3. The differences between the molecular weights and the mean molecular weight in the three cases are all less than 0.3 kg/kmol. If, however, the third replicate had yielded a molecular weight of 28.50 kg/kmol, averaging the values of 29.60, 29.61 and 28.50 would give a value of 29.23 and thus all the results would differ from the mean by more than 0.3 kg/kmol. In that case one or more further analyses would be required to meet the precision criterion and the third replicate of 28.50 would be discarded. Given the above data, the fourth and fifth replicates were unnecessary for the determination.

APPENDICES TO METHOD 3

Appendix 3A - Description of Orsat gas analyzer

(a)   Design
        There is a wide variety of acceptable Orsat analyzer designs on the market. In general, the Orsat will be similar to the design shown in Figure 14.
        Some specific design features which will increase the precision and accuracy of the Orsat analysis are as follows:
i)   The gas burette usually comprises a 50 ml portion that is graduated in 0.2 ml divisions; it is generally preferable that the burette has a 25 ml graduated portion with 0.1 ml divisions instead.
ii)   The volume reference mark should be located on the capillary tubing at the top of the gas burette rather than on the larger diameter burette.
iii)   The glass manifold should have as small a volume as possible to reduce the possibility of diluting the sample due to incomplete purging of the manifold.
iv)   The Orsat apparatus and case should be designed so that the levelling bottle and glass burette can be viewed side by side when levelling the liquid to ensure that the sample is at atmospheric pressure.
v)   The inlet sample valve should be a three-way valve to allow purging of the manifold without causing the sample bag or inlet gas to be diluted by ambient air.
(b)   Leak-Check
        The Orsat analyzer must be leak-checked each time it is moved from site to site, according to the following procedure:
i)   Bring the liquid level in each pipette up to the reference mark on the capillary tubing and then close the pipette stopcocks.
ii)   Raise the levelling bottle sufficiently to bring the confining liquid meniscus onto the graduated portion of the burette and then close the manifold stopcock.
iii)   Record the meniscus position.
iv)   Observe the meniscus in the burette and the liquid levels in the pipettes for movement over the next 4 minutes.
v)   The analyzer can be considered free of leaks, if the liquid level in each pipette does not fall below the bottom of the capillary tubing during the 4 minutes and the meniscus in the burette does not change by more than 0.2 ml during the 4 minutes.
vi)   If the analyzer is not free of leaks, the rubber connections and stopcocks should be checked until the cause of the leak is identified and eliminated.

(c)   Operation

The Orsat analyzer is operated according to the standard procedure. Absorbing reagents should be replaced after absorbing the following volumes of gas per milliliter of reagent:

potassium hydroxide   - 20 ml CO_2
potassium pyrogallate - 10 ml O_2
cuprous chloride   - 0.1 ml CO

If more than 10 passes are required to reach a constant reading for any one of the component gases, the test results should be disregarded and the applicable absorbing reagent replaced.
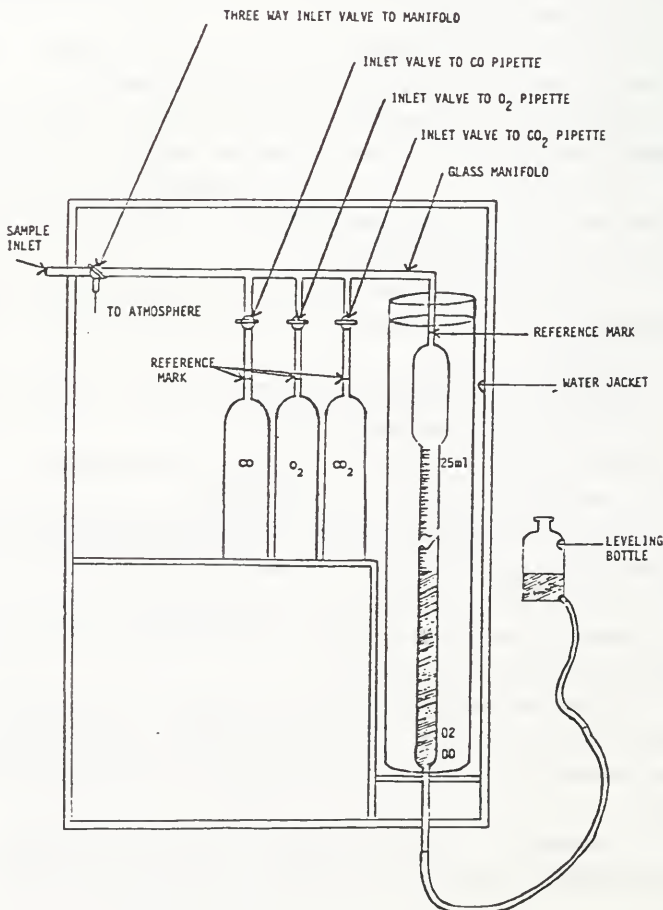

FIGURE 14. Illustration of key components of an Orsat analyzer for measuring CO_2, O_2, and CO contents of stack gases.

Appendix 3B - Analysis of stack gas by Orsat apparatus in the presence of
interferences

If the emission gases are analyzed with an Orsat analyzer, various gases may interfere with the accurate determination of the molecular weight. For example, acidic gases (e.g., SO_2, HCl) will absorb in the KOH solution along with CO_2, and inert gases other than nitrogen will be measured as nitrogen. Should these occurences not be accounted for, there will be an error in the molecular weight determination. In general, the concentration of an interfering non-atmospheric gas (e.g., SO_2 in the KOH solution or an inert gas as part of the N_2 fraction), results in a deviation greater than 0.3 kg/kmol from the actual molecular weight. For SO_2, this point is reached at a concentration of 1.5% and, if it is known or suspected that the SO_2 concentration is greater than 1.5%, SO_2 must be determined separately, subtracted from the CO_2 content as determined in the Orsat, and then included in the following molecular weight equation:

$$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.40(\%Ar) + 0.28(\%N_2 + \%CO) + 0.64(\%SO_2) \quad \text{eq. 3(4)}$$

Appendix 3C - Determination of molecular weight in stratified gases

Significant gas stratification in a stack or duct presents difficulties with regards to accurate source sampling, since the velocity determination depends on the molecular weight and the fixing of an isokinetic sampling rate depends on the calculated velocity. It may be necessary to determine the molecular weight at each individual sampling point. It may also be possible to use a multi-nozzle probe to obtain an integrated sample. The procedure used will depend on many factors and, if such a situation occurs, the Provincial Officer should be contacted to discuss the matter.

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METHOD 4

DETERMINATION OF MOISTURE CONTENT OF STACK GASES

METHOD 4
DETERMINATION OF MOISTURE CONTENT
OF STACK GASES

1.   PURPOSE

To determine the moisture content of stack gas.

2.   APPARATUS

i)   Probe - made of stainless steel, glass tubing or other material (stack conditions permitting) capable of being maintained at a minimum temperature of about 120°C (248 °F) and equipped with a filter, either in-stack (e.g., glass wool plug) or heated (120°C) out-stack filter similar to that in Method 5.

ii)   Condenser - comprising four impingers connected in series with leak-free fittings (e.g., ground glass); the first, third and fourth impingers are of the Greenburg-Smith design modified by replacing the tip with a glass tube about 1.3 cm (0.5 in.) I.D. extending to about 1.3 cm from the bottom of the flask; the second impinger is of the standard Greenburg-Smith design; a sensor capable of measuring temperature to within 3°C (5.4°F) is placed at the outlet of the fourth impinger; known volumes of water are placed in the first and second impingers and a known weight of desiccant is placed in the fourth impinger; the impingers are maintained in an ice bath; alternatively, functionally equivalent systems are acceptable.

iii)   Metering system - comprising a vacuum gauge, leak-free pump, calibrated dry gas meter capable of measuring volume to within 2% and including an inlet and an outlet temperature sensor (or temperature compensation); the sensors being capable of measuring temperature to within 3°C (5.4°F); an orifice meter for checking the instantaneous sampling rates and the dry gas meter calibration factor in the field; additional equipment as shown in Figure 15.

iv)   Barometer - capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg); alternatively the daily atmospheric pressure as provided by Environment Canada may be used, with an altitude adjustment for the sampling site at the rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 meters (100 ft) of elevation increase or vice versa for elevation decrease.

v)   Graduated cylinder - with subdivisions no greater than 2 ml.

4-2
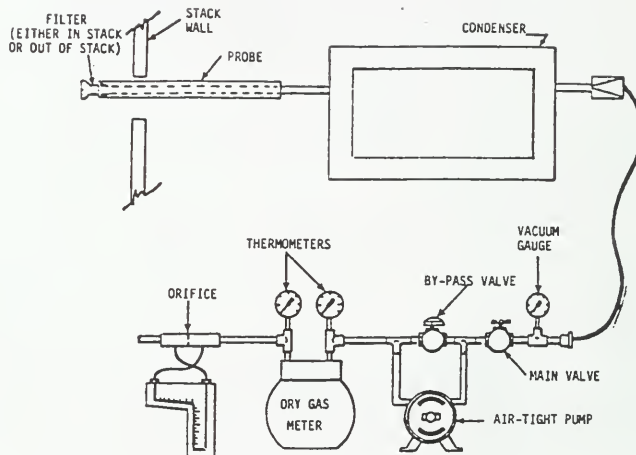
FIGURE 15. Moisture sampling train

vi)   Balance - capable of weighing to the nearest 0.5 g.

(NOTE: The standard particulate sampling train meets the requirements outlined in (i) to (iii).)

3.   PROCEDURE

A moisture determination performed according to the following procedure is required for any compliance test. In Appendix 4A, several methods for determining an approximate moisture content which may be used for setting isokinetic sampling are discussed.

i)   In general, a multi-point traverse is required for the purposes of this method. Sampling site location, number of sampling points and their location are determined according to Method 1.   However, methods for determination of specific pollutants may allow for moisture determination at a single sampling point.

ii)   Place 100 ml of water in each of the first two impingers and transfer 200

to 300 g of pre-weighed desiccant into the fourth impinger. A tared weighing procedure for desiccant plus impinger may be used. Volume is recorded to the nearest ml and weight to the nearest 0.5 g.

iii)   Assemble the moisture sampling train as shown in Figure 15. The orifice meter may be used to maintain a constant sampling rate. The dry gas meter must be calibrated according to the procedure in Appendix 4B and the calibration checked before each test series according to the procedure in Appendix 4C.

iv)   A total sampling time is selected such that a minimum total gas volume of 0.60 SCM (21 SCF) will be collected at a rate approximating the normal pollutant sampling rate. If performed simultaneously with a pollutant emission test using the same train, the moisture determination shall be continuous and for the same length of time as the emission test. If this method is being performed simultaneously with a particulate test using the same train, the sampling rate is isokinetic.

v)   Pre-heat the probe and out-stack filter heating system, if applicable, to a temperature of at least $120^{\circ}C$ ($248^{\circ}F$) to prevent water condensation ahead of the condenser. Allow time for the temperature to stabilize. Fill the ice bath just prior to sampling.

vi)   A pre-test leak-check is mandatory and is performed according to the following procedure:

a)   Plug the nozzle or inlet to the probe.

b)   Draw a vacuum of 380 mmHg (15 in. Hg), or the highest vacuum anticipated during the test. The recommended procedure for drawing a vacuum is to start the pump with the bypass valve fully open and the coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the bypass valve until the desired vacuum is reached. Do not reverse direction of the bypass valve, as this may cause water to flow into the filter holder.

c)   Maintain the vacuum for at least 2 minutes. A leakage rate of 0.00057 m^3/min (0.02 CFM) or greater is unacceptable and, if so found, the sampling train must be dismantled and reassembled until the leak is adequately reduced or eliminated.

d)   When the leak-check is completed, first slowly remove the plug from the nozzle or inlet to the probe and immediately turn off the vacuum pump. This prevents the water in the impingers from being forced into the filter holder or probe and silica gel from being entrained into the third impinger.

vii)   To being sampling, position the probe inlet at the first, or sole, sampling point. Immediately start the pump and adjust the flow to the desired rate as determined in section (iv). Traverse the cross-section, if required, and sample

at each point for an equal length of time. The sampling rate is maintained within 10% of a constant rate, or 10% of isokinetic rate when this method is being performed in conjunction with a pollutant test that requires isokinetic sampling.

viii)   Ensure that the temperature of the gas leaving the last impinger is less than $20^{\circ}C$ ($68^{\circ}F$). More ice and perhaps some salt may have to be added during the test to maintain a low gas temperature. Data are recorded according to the format shown in Figure 16. The dry gas meter volume readings are recorded at the beginning and the end of each sampling increment. Other required readings are taken at least once during each sampling increment.

ix)   After sampling for the required length of time, a post-test leak-check must be performed according to the procedure described in (vi) and modified in that the test vacuum is equal to or greater than the highest vacuum drawn during the test. If the leak-check is unacceptable, the test results must be discarded and the test repeated.

x)   Measure and record the volume of the condensed moisture to the nearest ml and the increase in weight of the desiccant to the nearest 0.5 g. Data are recorded according to the format shown in Figure 17.

4.   EQUATIONS FOR METHOD 4

The following equations are used to calculate the moisture content and stack gas molecular weight. If there are water droplets in the gas stream, it is assumed that the gas is saturated. In such a case the moisture content is determined from psychrometric tables and compared with the value determined by this method. The lower of the two values is the one used as the moisture content.

$$W_w \quad = \quad \text{weight of condensed } H_2O + \text{weight of } H_2O \text{ in desiccant} \qquad \text{eq. 4(1)}$$

S.I. Units

$$V_{w(ref)} \quad = \quad (1.36 \times 10^{-3})W_w \qquad\qquad \text{eq. 4(2)}$$

$$V_{w(ref)} \quad = \quad \text{volume of } H_2O, \text{ as gas, at 101.325 kPa and } 298^{\circ}K \text{ (m}^3)$$

$$V_{m(ref)} = \frac{2.94\ \gamma\ P_m V_m}{T_{m(avg)}} \qquad \text{eq. 4(3)}$$

$V_{m(ref)}$ = volume of gas sample at $298°K$ and $101.325\ kPa\ (m^3)$

γ = dry gas meter correction factor (See Appendix 4B)

V_m = volume of gas sample recorded on dry gas meter (m^3)

P_m = absolute pressure at dry gas meter (kPa) (for this method use barometric pressure)

$T_{m(avg)}$ = absolute temperature at dry gas meter $(°K)$ (the average of inlet and outlet temperatures recorded during each sampling increment or, if applicable, the meter compensation temperature)

$$B_{wo} = \frac{V_{m(ref)}}{V_{m(ref)} + V_{w(ref)}} \qquad \text{eq. 4(4)}$$

B_{wo} = volume fraction of H_2O in stack gas

$$M_s = M_d(1 - B_{wo}) + 18(B_{wo}) \qquad \text{eq. 4(5)}$$

M_s = molecular weight of stack gas (kg/kmol)

M_d = molecular weight of dry stack gas (kg/kmol)

British Units

$$V_{w(ref)} = 0.0480 W_w \qquad \text{eq. 4(6)}$$

$V_{w(ref)}$ = volume of H_2O, as gas, at 29.92 in. Hg and $537°R\ (ft^3)$

$$V_{m(ref)} = \frac{17.95 \, \gamma \, P_m \, V_m}{T_{m(avg)}} \qquad \text{eq. 4(7)}$$

$V_{m(ref)}$ = volume of gas sample at $537°R$ and 29.92 in. Hg (ft^3)

γ = dry gas meter correction factor (See Appendix 4B)

V_m = volume of gas sample recorded on dry gas meter (ft^3)

P_m = absolute pressure at dry gas meter (in. Hg) (for this method use barometric pressure)

$T_{m(avg)}$ = absolute temperature at dry gas meter ($°R$) (the average of inlet and outlet temperatures recorded during each sampling increment or, if applicable, the meter compensation temperature)

$$B_{wo} = \frac{V_{w(ref)}}{V_{m(ref)} + V_{w(ref)}} \qquad \text{eq. 4(8)}$$

B_{wo} = volume fraction of H_2O in stack gas

$$M_s = M_d(1 - B_{wo}) + 18(B_{wo}) \qquad \text{eq.4(9)}$$

M_s = molecular weight of stack gas (lb/lb-mole)

M_d = molecular weight of dry stack gas (lb/lb-mole)

5.   SAMPLE CALCULATIONS

Sample data for one traverse are recorded in Figure 16. Normally a second traverse is done and calculations are based on total sample volume and moisture collected on both traverses. Moisture data are recorded in Figure 17.

FIGURE 16. FIELD SAMPLING REPORT
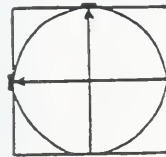
Plant*
Location*
Date*
Operators*
Run. No.*
Pitot Coefficient*
Dry Gas Meter Correction factor* 1.0

Schematic of stack cross-section; indicating coinpass direction, orientation of traverses and upstream flow disturbances

Ambient Temperature (°C)* 23C
Atmospheric Pressure, P bar (in. Hg)* 29.73
Assumed Moisture (%)
Static pressure, P static (in. H_2O)* - 0.4
Stack Diameter (ft)* 3.58
Nozzle Diameter (in.)
Probe Length (ft)
Probe Liner
Stack Gas Molecular Weight (lb/lb mol)

Traverse Number and Direction - I, N-S

Sampling Point Number*	Sampling Time* (Min.)	Stack Temp. T_s (°F)	Velocity Head ΔP, (in.H_2O) Low	Avg.	High	Orifice Pressure 'Drop,Δh' (in.H_2O)	Gas Sample Volume, Vm. (cu.ft.)	Dry Gas Meter Temperature Inlet T_M in (°F)	Outlet T_M out (°F)	Sample Box Temp. (°F)	Impinger Outlet Temp. (°F)	Probe Temp. (°F)	Vaccum (in.Hg.)
1	0	220					1734.39	70	70	250	65	250	3
	3	220					1736.46	71	70	250	65	250	3
	6	250					1738.50	72	71	250	66	250	3
2	9	250					1741.41	73	71	250	66	250	3
	12	250					1744.17	73	72	250	66	250	3
	15	250					1747.23	74	72	250	66	250	3
3	18	250					1750.48	75	72	250	66	250	3
	21	250					1753.43	76	73	250	66	250	3
4	24	250					1756.28	77	73	250	66	250	3
	27	250					1758.73	79	74	250	66	250	3
5	30	250					1761.03	80	74	250	66	250	3.5
	33	255					1763.51	82	75	250	66	250	3.5
6	36	255					1765.90	83	76	250	66	250	3.5
	39	255					1768.19	85	76	250	66	250	3.5
7	42	250					1770.52	85	77	250	66	250	3.5
	45	250					1772.92	86	77	250	66	250	3.5
8	48	250					1775.22	87	78	250	66	250	3.5
								Avg. 77.7	avg. 73.6				

* Information required for Method 4

FIGURE 17. Moisture Data

	Final Weight (g)	Tare Weight (g)	Weight of Moisture (g)
impinger #1:	579.5	537.4	42.1
impinger #2:	631.2	565.8	65.4
impinger #3:	485.9	484.3	1.6
impinger #4:	623.0	612.0	<u>11.0</u>
		TOTAL :	120.1

$$V_m \quad = \quad 1775.22 - 1734.39$$
$$= \quad 40.83 \text{ ft}^3$$

$$P_m \quad = \quad P_{bar}$$
$$= \quad 29.73 \text{ in. Hg}$$

$$V_{m(ref)} \quad = \quad \frac{17.95 \, \gamma \, P_m \, V_m}{T_{m(avg)}}$$
$$= \quad \frac{(17.95)\,(1.0)\,(29.73)\,(40.83)}{535.65}$$
$$= \quad 40.68 \text{ ft}^3$$

$$V_{w(ref)} \quad = \quad 0.0480 W_w$$
$$= \quad 0.0480\,(120.1)$$
$$= \quad 5.76 \text{ ft}^3$$

$$B_{wo} = \frac{V_{w(ref)}}{V_{m(ref)} + V_{w(ref)}}$$

$$= \frac{5.76}{40.68 + 5.76}$$

$$= 0.124$$

If the molecular weight of the dry stack gas is determined to be 29.60 lb/lb-mole then:

$$M_s = M_d(1 - B_{wo}) + 18(B_{wo})$$

$$= 29.60(0.876) + 18(0.124)$$

$$= 28.16 \text{ lb/lb-mole}$$

APPENDICES TO METHOD 4

Appendix 4A - Approximation methods for determination of moisture content

The following procedures may be used to determine the moisture content of a stack gas for the purposes of setting isokinetic sampling rates.

i) previous experience

ii) mass balance calculations

iii) drying tubes

iv) wet and dry bulb thermometer technique - can be used if stack gas temperature is less than $100^{\circ}C$ ($212^{\circ}F$), the gas stream velocity is greater than 5 m/sec. (15 ft/sec.) and the gas stream does not contain water droplets or acid mist.

v) condensation techniques - e.g., 2 midget impingers in an ice bath, as shown in Figure 18; note that, if the silica gel tube moisture content is not determined, the calculated value for B_{wo} must be increased by the moisture content of saturated gas at the temperature of the gas leaving the second impinger. $70^{\circ}F$ may be used as an estimate or a temperature sensor can be placed at the outlet of the second impinger. At $70^{\circ}F$ the moisture content of saturated gas is 0.025.
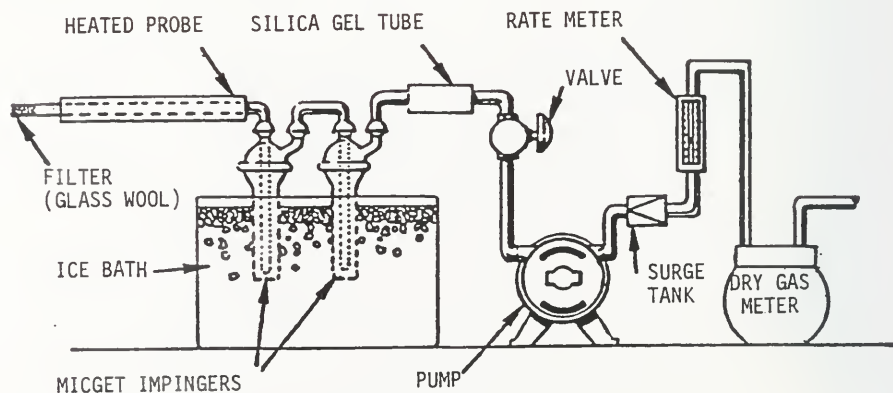
FIGURE 18.   Moisture sampling train - approximation method

Appendix 4B - Calibration of dry gas meter and determination of orifice
coefficient

The dry gas meter is calibrated at least once every six months against a standard capable of measuring volume within ± 1% accuracy, at a rate approximating that of the dry gas meter. The standard is either a primary standard or a device calibrated against a primary standard. For example, a calibrated wet test meter may be used, as illustrated in the following procedure:

i)   Assemble the components as shown in Figure 19. The components within the broken lines are usually integrated in the control unit of a standard particulate sampling train.
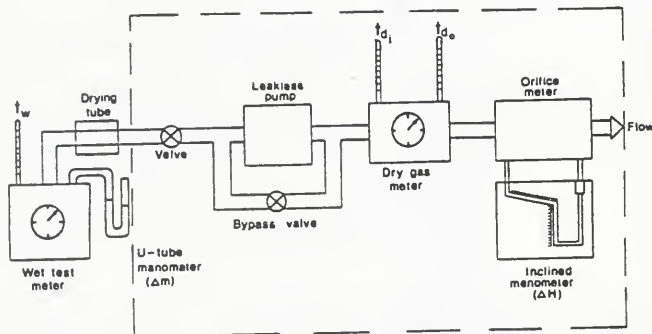
FIGURE 19. Assembly for calibration of dry gas meter

ii)   Operate the equipment with the orifice manometer set at 13 mm H_2O (0.5 in. H_2O) for at least 15 minutes to ensure that the pump is at operating temperature and all interior surfaces of the wet test meter are wetted.

iii)   Perform tests and record data according to the requirements of Figure 20, i.e. draw the required volume of air at the stated orifice manometer setting and record the volume through the gas meter, the time required to draw the required volume and the other parameters.

iv)   Moisture content of the air may be determined by any practical means, e.g.

FIGURE 20. DRY GAS METER CALIBRATION AND ORIFICE COEFFICIENT DATA

Date:
Barometric Pressure in. Hg or kPa :
Dry Gas Meter Number:

Orifice Manometer Setting, ΔH in.H_2O or cm H_2O		Gas Volume Standard V_w, ft^3 or m^3	Gas Volume Dry Gas V_d, ft^3 or m^3	Temperature °F or °C Standard (Wet) t_w	Temperature °F or °C Dry Gas Meter Inlet t_{di}	Temperature °F or °C Dry Gas Meter Outlet t_{do}	Temperature °F or °C Dry Gas Meter Ave. t_d	Time θ Minutes	Standard (Wet) Manometer Reading Δm in.H_2O or cm H_2O	Meter Correction Factor γ	Orifice Coefficient K_o Metric or British
0.5	1.3	5	.15								
1.0	2.5	5	.15								
2.0	5.0	10	.30								
4.0	10.0	10	.30								
6.0	15.0	10	.30								
8.0	20.0	10	.30								

the wet and dry bulb technique adequately accurate for ambient air.

v)   Calculate γ for each test volume by using either eq. 4(10) (S.I. Units) or eq. 4(11) (British Units):

$$\gamma = \frac{V_w(P_{bar} + 0.098\,\Delta M)\,(t_d + 273)\,(1 - B_{wo})}{V_d(P_{bar} + 0.098\,\Delta H)\,(t_w + 273)} \qquad \text{eq. 4(10)}$$

or

$$\gamma = \frac{V_w(P_{bar} + \frac{\Delta M}{13.6})\,(t_d + 460)\,(1 - B_{wo})}{V_d(P_{bar} + \frac{\Delta H}{13.6})\,(t_w + 460)} \qquad \text{eq. 4(11)}$$

where γ = dry gas meter correction factor

       V_w = volume recorded by standard (m^3 or ft^3)

       V_d = volume recorded by dry gas meter (m^3 or ft^3)

       P_{bar} = barometric pressure (kPa or in. Hg)

       ΔM = standard wet test meter manometer reading (cm H_2O or in. H_2O)

       ΔH = dry gas meter orifice manometer reading (cm H_2O or in. H_2O)

       t_d = average of inlet and outlet temperatures at dry gas meter (^oC or ^oF)

       t_w = temperature at standard (^oC or ^oF)

       B_{wo} = moisture fraction of air .

vi)   Calculate the average γ by graphing Q(standard) versus Q(dry), where Q(standard) equals the numerator of either eq. 4(10) or eq. 4(11) divided by the time θ and Q(dry) equals the denominator of the respective equation divided by θ ; the slope of the best fitting line is the average γ . A more accurate means of determining the average γ is to determine the best fitting line by first order linear regression. If all individual values of γ are within $\pm 2\%$ of the average, then the calibration is acceptable. If this criterion cannot be met, it may be necessary to have the dry gas meter internally adjusted and recalibrated.

vii)   Calculate K_o for each test volume by using either eq. 4(12) or eq. 4(13) from data used to calculate an acceptable γ .

$$K_o = \frac{\dfrac{\gamma_{(avg)}\, V_d\, (t_{do} + 273)}{\theta\, (t_d + 273)}}{\sqrt{\dfrac{\Delta H(t_{do} + 273)}{M(P_{bar} + 0.098\,\Delta H)}}} \qquad \text{eq. 4(12)}$$

or

$$K_o = \frac{\dfrac{\gamma_{(avg)}\, V_d\, (t_{do} + 460)}{\theta\, (t_d + 460)}}{\sqrt{\dfrac{\Delta H(t_{do} + 460)}{M(P_{bar} + \dfrac{\Delta H}{13.6})}}} \qquad \text{eq. 4(13)}$$

where K_o = orifice coefficient (different values for metric and British units)

$\gamma_{(avg)}$ = average dry gas meter correction factor

M = molecular weight of air

θ = time (minutes)

viii) Calculate the average K_o arithmetically.

Appendix 4C – Dry gas meter calibration check

Before each test series, the dry gas meter correction factor must be checked on the sampling site according to the following procedure:

i) At at least three different orifice manometer settings approximately covering the range of values expected in the test series, draw ambient air sample volumes, each for a duration of at least three minutes. Record the dry gas meter volume, the time period, the ΔH, the orifice temperature (equal to temperature leaving the dry gas meter) and the dry gas meter temperature.

ii) Determine the ratio, R, of the dry gas meter volumetric flow rate versus the orifice flow rate using the values for $\gamma_{(avg)}$ and K_o as determined in Appendix 4B. Use eq. 4(14) for metric calculations and eq. 4(15) for British.

$$R = \frac{\dfrac{\gamma_{(avg)} \, V_d \, (t_{do} + 273)}{\theta \, (t_d + 273)}}{K_o \sqrt{\dfrac{\Delta H(t_{do} + 273)}{M(P_{bar} + 0.098 \, \Delta H)}}} \qquad \text{eq. 4(14)}$$

$$R = \frac{\dfrac{\gamma_{(avg)} \, V_d \, (t_{do} + 460)}{\theta \, (t_d + 460)}}{K_o \sqrt{\dfrac{\Delta H(t_{do} + 460)}{M(P_{bar} + \dfrac{\Delta H}{13.6})}}} \qquad \text{eq. 4(15)}$$

If the value of R is 1.0 ± 0.05 the meter correction factor is acceptable for use in the following test series. Otherwise, the meter must be recalibrated before use.

Bibliography

1. Environmental Protection Agency, Standards of Performance for New Stationary Sources, Federal Register, Part II, Vol. 42, No. 160, pp. 41754 - 41782, Aug. 18, 1977.

2. Environment Canada, Report EPS 1-AP-74-1, Standard Reference Methods for Source Testing: Measurement of Emissions of Particulates from Stationary Sources, February, 1974.

3. Ministry of the Environment, Province of Ontario, Source Testing Code, January 1973.

4. Canadian Standards Association, CSA Standard Z223.1 - M1977, Method for the Determination of Particulate Mass Flows in Enclosed Gas Streams, October, 1977.

METHOD 5

DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

METHOD 5
DETERMINATION OF PARTICULATE EMISSIONS
FROM STATIONARY SOURCES

1.   PURPOSE

To determine the particulate concentration of a gas stream in a stack or duct and the particulate emission rate, using an isokinetic sampling technique and an out-stack glass fibre filter which is maintained at a temperature of $120^{\circ}C$ ($248^{\circ}F$). The particulate mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after removal of uncombined water.

2.   LIMITATIONS

This method is not applicable per se in the following cases:
i)   Gas streams containing significant concentrations of one or more substances with a dew point greater than $120^{\circ}C$ ($248^{\circ}F$).
ii)   Non-continuous processes
Where either of the above situations occur reference is to be made to the appendices.

3.   APPARATUS

Sampling Train

Commercially available sampling trains generally are comprised of the individual components shown in Figure 21. Such trains are acceptable for use with this method. Specifically, the required components for this method are:
i)   Probe Nozzle - stainless steel (316, seamless) or glass, with a sharp, tapered leading edge; button-hook or elbow design; a range of nozzles should be available to allow for isokinetic sampling at sources with different gas velocities, e.g., 0.3175 cm to 1.27 cm (1/8 in. to 1/2 in.).
ii)   Probe - structurally stable, long enough to traverse at least half of the stack diameter, capable of maintaining a gas temperature of $120^{\circ}C$ ($248^{\circ}F$) at the exit end during sampling and including a probe temperature sensor; lined with

borosilicate or quartz glass, if the stack temperature is less than 480°C (900°F); and quartz glass, if more than 480°C (900°F) and less than 900°C (1650°F); alternatively, corrosion resistant metal liners may be used; probe is usually sheathed for protection and insulation; may be water cooled, if required.

iii)   Pitot tube - S-type (Stausscheibe or reverse type) or standard type; reference should be made to Method 2 concerning pitot and probe assembly (pitot, temperature sensor and nozzle) configuration and calibration.

iv)   Temperature sensor - thermocouple or other calibrated device capable of measuring stack gas temperature to within 1.5% of the minimum temperature; sensor is fixed to the probe assembly so that the tip of the sensor extends beyond the probe sheath and does not touch any metal; temperature sensor must be checked according to the procedure of Appendix 2E.

v)   Differential pressure gauges - two inclined manometers or devices of equivalent sensitivity, readable to the nearest 0.13 mm H_2O (0.005 in. H_2O) for ΔP values between 0.13 and 25 mm H_2O (0.005 to 1.0 in. H_2O) and readable to the nearest 1.3 mm H_2O (0.05 in. H_2O) for ΔP values greater than 25 mm H_2O (1.0 in. H_2O); a more sensitive gauge is required if a ΔP reading is found to be less than 5 smallest scale divisions; see Appendix 2B regarding calibration of differential pressure gauges other then manometers and Appendix 2C regarding more sensitive gauges.
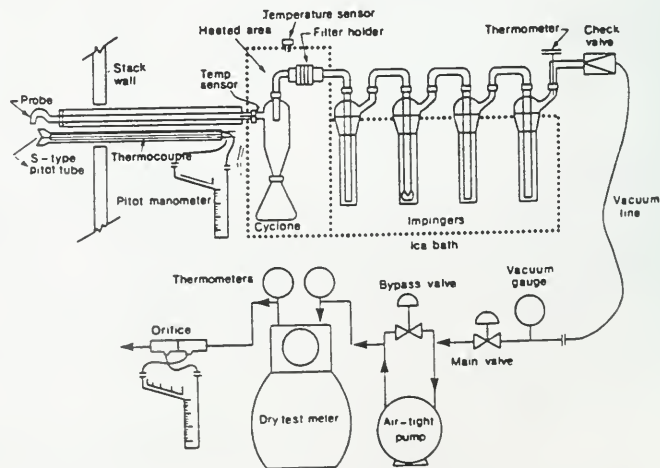

FIGURE 21. Particulate sampling train

vi)   Filter holder - borosilicate glass with a glass or sintered stainless steel frit filter support and silicone rubber gasket (other inert materials may be used); designed to avoid leakage around the filter.

vii)   Miniature cyclone - optional, although it should be used when the particulate catch is expected to exceed 100 mg.

viii)   Filter and cyclone heating system - capable of maintaining a temperature of 120°C (248°F) around the filter holder and cyclone (if used) during sampling and including a temperature gauge capable of measuring to within 3°C (5.4°F) to enable monitoring and regulation of the temperature.

ix)   Condenser - comprising four impingers connected in series with leak-free fittings (e.g., ground glass); the first, third and fourth impingers are of the Greenburg-Smith design modified by replacing the tip with 1.3 cm (0.5 in.) I.D. glass tubing extending to about 1.3 cm from the bottom of the flask; the second impinger is of the standard Greenburg-Smith design; a sensor capable of measuring temperature to within 1°C (1.8°F) is placed at the outlet of the fourth impinger; known volumes of water are placed in the first and second impingers and a known weight of desiccant is placed in the fourth impinger; the impingers are maintained in an ice bath; alternatively, functionally equivalent systems are acceptable.

x)   Metering system - comprising a vacuum gauge, leak-free pump with coarse and fine control valves, calibrated dry gas meter capable of measuring volume to within 2% and including an inlet and an outlet temperature sensor (or temperature compensation), the sensors being capable of measuring temperature to within 3°C (5.4°F), and a calibrated orifice meter.

xi)   Barometer - capable of measuring atmospheric pressure to within 2.5 mm (0.1 in.) Hg; alternatively, the daily atmospheric pressure is provided by Environment Canada may be used with an altitude adjustment for the sampling site at the rate of minus 2.5 mm (0.1 in.) Hg per 30 meters (100 ft) of elevation increase or vice versa for elevation decrease.

xii)   Gas composition determination equipment - See Methods 3 and 4.

Sample Recovery and Analysis Equipment

xiii)   Filters - glass fibre without organic binder, exhibiting at least 99.95 percent efficiency (<0.05 percent penetration) on 0.3 micron dioctyl phthalate smoke particles (manufacturer's test data are sufficient).

xiv)   Brushes - sized and shaped to clean out probe and nozzle; nylon bristles

with stainless steel wire handle and extensions of stainless steel, Nylon*, Teflon*, or other inert material.

xv) Wash bottles - glass or polyethylene; acetone should not be stored in poly-ethylene longer than one month.

xvi) Liquid sample storage containers - glass or polyethylene (500 or 1000 ml) with leak-free acetone resistant caps; acetone samples should not be stored in polyethylene longer than one month.

xvii) Petri dishes - glass or polyethylene, large enough to hold unfolded filter.

xviii) Graduated cylinder - with subdivisions no greater than 2 ml.

xix) Balance - capable of weighing to the nearest 0.5 g.

xx) Desiccant containers - air tight.

xxi) Funnel and rubber policeman.

xxii) Desiccator

xxiii) Analytical balance - capable of weighing to the nearest 0.1 mg.

xxiv) Desiccant - new or fully regenerated, self-indicating, e.g., 6 to 16 mesh indicating type silica gel.

xxv) Stopcock grease - heat-stable silicone grease insoluble in acetone.

xxvi) Acetone - reagent grade, 0.001% residue, in glass bottles.

4. PROCEDURE

Preparation

i) The pitot tube (probe assembly), dry gas meter and orifice meter must be maintained in accordance with standard accepted procedures and calibrated prior to testing, in accordance with Appendices 2A and 4A. Such calibration data must be available on request, prior to or during the actual testing and also must be submitted with the final report.

ii) Filters are checked visually against a light for irregularities and flaws or pinhole leaks. They are identified by appropriate labeling of their shipping containers (petri dishes).

iii) Filters are desiccated at $20^{\circ}C \pm 6^{\circ}C$ ($68^{\circ}F \pm 10^{\circ}F$) and ambient pressure for at least 24 hours and then weighed at intervals of at least 6 hours to a constant weight, i.e. 0.5 mg change from the previous reading; weight of filters is

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* Trade Mark - E.I. DuPont de Nemours & Co.

recorded to the nearest 0.1 mg; record the filter weighing room relative humidity which must not exceed 50% during weighing; the filter should not be exposed to the ambient atmosphere for longer than 2 minutes. An alternative procedure is to oven dry the filters at 105°C (220°F) for 2 to 3 hours, desiccate for 2 hours and then weigh to a constant weight, as above.

iv)   Weigh the cyclone collection flask, if used, and record the weight to the nearest 0.1 mg.

v)   Select the sampling site location and number of sampling points in accordance with Method 1.

Preliminary Survey

vi)   A preliminary survey must be performed to determine gas flow parameters in order to prepare for actual sampling at isokinetic rates. Gas temperature, molecular weight, static pressure and the velocity profile (including cyclonic flow check) are required parameters for this purpose. It is also important to know the range of particulate loading so that a sampling period can be established.

The parameters noted above can be determined by performance of Methods 2 to 5. For this purpose Method 5 may be modified. For example, total sampling time may be reduced by decreasing the number of sampling points or the sampling time per point. The information learned from such a test would include the gas temperature, velocity profile, moisture content and particulate loading. From this information, assuming the parameters of the source remain constant, isokinetic sampling rates can be calculated and the proper nozzle size determined. Also, the sampling period can be determined so as to meet the minimum criteria for particulate catch or total gas volume sampled.

Portions of the preliminary survey do not have to be performed, if it can be shown that the respective parameters are known to a satisfactory degree of accuracy. Written documentation should be provided.

The nozzle size must be selected so that it is not necessary to change the nozzle during the sampling test in order to achieve isokinetic sampling. As well, the probe liner and probe length should be suitable for the conditions of the gas stream and the size of the stack or duct. With very large cross-sections it may be necessary to perform four half-diameter traverses.

The minimum criteria for the actual testing period are:

a)   sampling for 5 minutes per traverse point

b)   25 mg of particulate catch with at least 1.7 dry standard m^3 (60 DSCF) of stack gas or 3.4 dry standard m^3 (120 DSCF) of stack gas

More than 5 minutes per point may be necessary to achieve criterion (b).

Preparation of Sampling Train

vii)   Place about 100 ml of distilled or deionized water in each of the first two impingers and weigh each of the first three impingers and record to the nearest 0.5 g or measure the volume of water in each impinger to the nearest 1 ml.

viii)   Place 200 to 300 g of desiccant in the fourth impinger, the weight being taken either directly or as the tared weight of desiccant and impinger and recorded to the nearest 0.5 g.

ix)   Place a weighed and identified filter in the filter holder using a pair of tweezers or clean disposable surgical gloves; the filter must be centered and the gasket properly placed so as to prevent the sample gas stream from circumventing the filter.

x)   Assemble the sampling train, keeping all openings where contamination could occur covered until just prior to assembly or until sampling is about to begin. A very light coating of silicone grease should be applied to all ground glass joints, greasing only the outer portion to avoid the possibility of contamination by the silicone grease.

xi)   A pre-test leak-check is mandatory and is performed according to the following procedure:

a)   Plug the nozzle or inlet to the probe.

b)   Draw a vacuum of 380 mm (15 in.) Hg (or the highest vacuum anticipated to occur during the test). The recommended procedure for drawing a vacuum is to start the pump with the bypass valve fully open and the coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the bypass valve until the desired vacuum is reached. Do not reverse direction of the bypass valve; this will cause water to back up into the filter holder.

c)   Maintain the vacuum for at least 2 minutes. A leakage rate of 0.00057 m^3/min (0.02 CFM) or greater is unacceptable and, if so found, the sampling train must be dismantled and reassembled until the leak is adequately reduced or eliminated.

d)   When the leak-check is completed, slowly remove the plug from the nozzle or inlet to the probe and immediately turn off the vacuum pump. This

prevents the water in the impingers from being forced into the filter holder (if placed before the impingers) and silica gel from being entrained into the third impinger.

xii) Prior to sampling, suitable means should be provided to enable as exact positioning of the probe at the sampling points as possible, during the actual test. Clean the portholes prior to the test run to minimize the chance of sampling deposited material.

Sampling Train Operation

xiii) Start the probe and filter heating systems and before commencing the test verify that both units are maintained at a temperature of $120^{o}C$ ($248^{o}F$); place crushed ice around the impingers (if this type of condensing apparatus is used).

xiv) Remove any protective covering from the nozzle and position the nozzle at the first sampling point, ensuring that all components of the probe assembly are properly oriented with respect to the gas stream, i.e., nozzle and pitot face opening planes are perpendicular to the direction of flow. Block off openings around the probe and porthole to prevent dilution of the gas stream.

xv) Immediately start the pump and adjust the flow rate to isokinetic conditions. The various methods for calculating isokinetic rates are discussed in Appendix 5A. If the stack is under significant negative pressure (several centimeters of H_2O) take care to close the coarse adjust valve before inserting the probe into the stack to prevent water from backing into the filter holder. If necessary, the pump may be turned on with the coarse adjust valve closed.

xvi) Traverse the stack cross-section as required by Method 1. It is recommended to start at the furthest point from the port. Ensure that the probe nozzle does not contact the stack walls or port, thus minimizing the chance of extracting deposited material. Sample at each sampling point for 5 minutes, or longer, if necessary. As soon as the probe has been moved to the next point adjust the flow rate to isokinetic conditions.

xvii) For each traverse, data are recorded according to the format shown in Figure 22. These data shall be recorded at least twice for each sampling point and the length of the time period between recordings shall be between 2.0 and 3.0 minutes. (When the point velocities and temperatures are not fluctuating the time period can be increased, pending the permission by Provincial Officer.) The dry gas meter volume is recorded at the start of the test and at the end of each of these time periods.   The other information in the various columns is recorded

at some time during each of the periods. During each of these periods, the sampling rate through the train must be 100% ± 10% of the isokinetic sampling rate. Each time the probe is moved to a different point with another velocity pressure reading; the sampling rate must be adjusted. Similarly, the sampling rates must be adjusted, and a record of such adjustment made, whenever significant step changes in point velocities or temperatures are noted. Deviations from the ideal isokinetic sampling rate may be determined using either eq. 5(5) or eq. 5(10).

xviii) During the test run, ensure that the probe and filter housing are maintained at 120°C (248°F) and that the temperature at the outlet of the impingers is less than 20°C (68°F). It may be necessary to add more ice and possibly salt to attain the required temperature. Periodically check the level and the zero of the manometer.

xix) If the pressure drop across the filter becomes too high, making isokinetic sampling difficult to maintain, the filter may be replaced in the midst of a sampling run; similarly, a full cyclone flask or spent silica gel must be replaced. Another complete filter assembly should be used rather than attempting to change the filter itself. Leak-checks must be conducted both before a new component is installed and also before sampling is resumed. The original and substituted components are added together to determine the total weight.

xx) At the end of the traverse, turn off the course adjust valve, record the final dry gas meter reading, remove the probe and nozzle from the stack, turn off the pump, and conduct a post-traverse leak-check.

xxi) Repeat steps xvi) to xx) for the second (or more) traverses except that a pre-traverse leak-check is not required. However, it is recommended that pre-traverse leak-checks be performed, since the movement of the sampling train from one port to another may cause leaks.

Sample Recovery

xxiii) Upon removing the probe from the port, and having conducted a leak-check, pull ambient air through the train to purge any gases absorbed in impinger water and allow the sampling train to cool until it can be safely handled. Wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it to prevent the loss or contamination of the sample. The probe tip should not be tightly capped while the sampling train is cooling as this would create a vacuum in the filter holder, thus drawing water from the impingers into the filter holder.

xxiv) Remove the probe from the sampling train and cover the exposed end, being

careful not to lose any sample in the probe. Remove the umbilical cord. Wipe any silicone grease from the filter or cyclone inlet and last impinger outlet and cover these openings.

xxv) The probe and filter-impinger assembly should be removed to a clean and sheltered area; inspect the components and note any damage or abnormalities.

xxvi) The filter is carefully removed from the filter holder, using a pair of tweezers and/or clean disposable surgical gloves, and placed in its identified container (for the purposes of this procedure, hereinafter referred to as container no. 1). Any particulate or filter matter adhering to the filter holder gasket must also be removed with a brush and a sharp edge and placed with the filter. Seal the container.

xxvii) If a cyclone was used, remove the cyclone collection flask and seal it.

xxviii) Completely recover particulate matter and any condensate from the front end, i.e. the probe nozzle, fittings, probe liner and front half of the filter holder, by washing these components and placing the wash in a container designated as container no. 2. Specifically: carefully remove the nozzle and fittings and clean the inside surfaces by rinsing with acetone from a wash bottle and then brush; the procedure is continued until the washings show no visible particles; the probe liner is cleaned by first tilting and rotating the probe while squirting acetone into the upper end as the probe brush is being pushed with a twisting action through the probe; the acetone washing is collected in container no. 2; this brushing action is repeated until the washings show no visible particles; after ensuring that all the silicone grease has been removed, clean the front half of the filter holder by rubbing the surfaces with a brush and rinsing with acetone repeatedly until the washings show no particles; the cyclone is similarly washed and after final use the brush is rinsed; these washings are also collected in container no. 2. At the completion of washing the front end, container no. 2, is sealed.

xxix) Disassemble the impinger train and remove any silicone grease from the joints; note and report the condition of the silica gel, i.e., the extent of saturation and then transfer it to container no. 3 and seal; rubber policeman may be used to aid in the complete transfer. If a tared weighing procedure was initially used, immediately weigh the impinger and its contents or seal the impinger for later weighing.

xxx) Measure and record the amount of liquid caught in the first three impingers to the nearest 0.5 g or 1.0 ml and then retain this liquid in a container no. 4. Wash the back half of the filter holder with water and rinse the 3 impingers with deionized or distilled water and add these washings to container no. 4.

Laboratory Analysis

xxxi) Desiccate the contents of container no. 1 and the cyclone collection flask, if used, for 24 hours at $20^{\circ}C \pm 6^{\circ}C$ ($68^{\circ}F \pm 10^{\circ}F$) and ambient pressure and then weigh them at intervals of at least 6 hours to a constant weight, i.e. < 0.5 mg change from the previous reading, and report the weights to the nearest 0.1 mg; record the weighing room relative humidity, which must not exceed 50%; samples should not be exposed to the ambient atmosphere for longer than 2 minutes. An alternative procedure is to oven dry at $105^{\circ}C$ ($220^{\circ}F$) for 2 to 3 hours, desiccate for 2 hours and then weigh to a constant weight, as above.

xxxii) If the sampled particulate matter is hygroscopic, a constant weight may be impossible to achieve. If this situation is encountered, the dry weight may be determined by weighing the sample at specific time intervals after removal from the desiccator, e.g., every 30 seconds, plotting the weight versus the time from removal and then extrapolating the graph to time zero to determine the desiccated weight.

xxxiii) Transfer the contents of container no. 2 to a tared beaker and evaporate to dryness at ambient temperature and pressure. Transfer the contents of container no. 4 to a tared beaker and evaporate to dryness at $95^{\circ}C$ ($203^{\circ}F$); avoid violent bubbling. Desiccate and weigh both beakers to a constant weight as was done for the filter, and record the weights to the nearest 0.1 mg.

xxxiv) Weigh the silica gel from container no. 3 or the impinger containing the silica gel (if not done on site) and report the weight to the nearest 0.5 g.

xxxv) Retain all samples for at least 6 months after the test series. They are to be made available upon request. Analysis data are recorded as shown in Figure 23. Note that the particulate matter found in container no. 4 is not to be included in determination of emissions unless so specified by the Provincial Officer.

xxxvi) Determine and report the particulate concentration and particulate emission rate using the following equations.

5.   EQUATIONS FOR METHOD 5

S.I. Units

$$P_{m(avg)} = P_{bar} + 0.098 \; \Delta H_{(avg)} \qquad\qquad \text{eq. } 5(1)$$

where $P_{m(avg)}$ =   average absolute pressure at the dry gas meter
throughout the test (kPa)

P_{bar} =   barometric pressure (kPa)

$\Delta H_{(avg)}$ =   average of recorded orifice pressure differentials
(cm H_2O)

$$V_{m(ref)} = \frac{2.94 \; \gamma \; P_{m(avg)} V_m}{T_{m(avg)}} \qquad\qquad \text{eq. } 5(2)$$

where $V_{m(ref)}$ =   volume of gas sample at 298°K and
101.325 kPa (m^3)

γ =   dry gas meter correction factor

V_m =   volume of gas sample recorded on dry gas meter
(m^3)

$T_{m(avg)}$ =   absolute temperature at dry gas meter (°K)
(the average of inlet and outlet temperatures
recorded during each sampling increment or if
temperature compensation, that temperature)

$$C_s = \frac{10^{-6} \; M_p}{V_{m(ref)}} \qquad\qquad \text{eq. } 5(3)$$

where C_s =   concentration of particulate matter in stack
gas on a dry gas basis at 298°K and 101.325 kPa in
kg/m^3

M_p =   weight of particulate matter from nozzle, probe
liner, cyclone, front half of filter holder and filter
(may include back half and impingers if requested
by the Provincial Officer)(mg)

$$ER_p = C_s Q_s \qquad\qquad \text{eq. 5(4)}$$

where $\quad Q_s \quad$ = volumetric flow rate of dry stack gas at $298^{\circ}K$
and 101.325 kPa in m^3/hr (See Method 2, eq. 2(3))

$\qquad\quad ER_p \quad$ = emission rate of particulate matter (kg/hr)

$$\%I = \frac{T_s \left(\dfrac{DGMV}{t} \right)(\gamma)\left(\dfrac{1}{1-B_{wo}} \right) (P_{bar} + 0.098\,\triangle H)(100)}{(4.71 \times 10^{-3})\, T_m\, P_s\, U_s\, D_N^2} \qquad\qquad \text{eq. 5(5)}$$

NOTE: % I is calculated for each set of readings and used to obtain the average
% I for the test

$\quad \%I \quad$ = percentage of isokinetic sampling rate

$\quad DGMV \quad$ = incremental volume increase on dry gas meter
during period t (m^3)

$\quad t \quad$ = incremental sampling period (min.)

$\quad B_{wo} \quad$ = volume proportion of water in stack gas

$\quad \triangle H \quad$ = orifice pressure differential during period t
(cm H_2O)

$\quad T_s \quad$ = absolute stack gas temperature during period
t $(^{\circ}K)$

$\quad D_N \quad$ = diameter of nozzle opening (cm)

$\quad T_m \quad$ = absolute temperature at dry gas meter (average
of temperatures at inlet and outlet) during period
t $(^{\circ}K)$

$\quad P_s \quad$ = absolute stack gas pressure (kPa)

$\quad U_s \quad$ = stack gas velocity (m/sec)(See eq. 2(2))

British Units

$$P_{m(avg)} = P_{bar} + \frac{\Delta H_{(avg)}}{13.6} \qquad \text{eq. 5(6)}$$

where $P_{m(avg)}$ = average absolute pressure at the dry gas meter throughout the test (in. Hg)

           P_{bar} = barometric pressure (in. Hg)

           $\Delta H_{(avg)}$ = average of recorded orifice pressure differentials (in. H_2O)

$$V_{m(ref)} = \frac{17.95 \; \gamma \; P_{m(avg)} \; V_m}{T_{m(avg)}} \qquad \text{eq. 5(7)}$$

where $V_{m(ref)}$ = volume of gas sample at $537^{o}R$ and 29.92 in. Hg (ft^3)

           γ = dry gas meter correction factor

           V_m = volume of gas sample recorded on dry gas meter (ft^3)

           $T_{m(avg)}$ = absolute temperature at dry gas meter (^{o}R) (the average of inlet and outlet temperatures recorded during each sampling increment or if temperature compensated that temperature)

$$C_s = \frac{(2.205 \times 10^{-6}) \; M_p}{V_{m(ref)}} \qquad \text{eq. 5(8)}$$

where C_s = concentration of particulate matter in stack gas on a dry gas basis at $537^{o}R$ and 29.92 in. Hg (lb/ft^3)

           M_p = weight of particulate from: nozzle, probe liner, cylone, front half of filter holder and filter (may include back half and impingers if requested by the Provincial Officer)(mg)

$$ER_p = C_s Q_s \qquad\qquad\qquad \text{eq.5(9)}$$

Q_s = stack gas volumetric flow rate on a dry gas basis at $537^{\circ}R$ and 29.92 in. Hg (See Method 2 eq. 2(6))

ER_p = emission rate of particulate matter (lb/hr)

$$\%I = \frac{T_s \left(\dfrac{DGMV}{t}\right)(\gamma)\left(\dfrac{1}{1 - B_{wo}}\right)\left(P_{bar} + \dfrac{\Delta H}{13.6}\right)(100)}{0.3272\, T_m\, P_s\, U_s\, D_n^{2}} \qquad\qquad \text{eq. 5(10)}$$

$\%I$ = percentage of true isokinetic sampling rate

NOTE: $\%I$ is calculated for each set of readings and used to obtain the average $\%I$ for the test.

DGMV = incremental volume increase on dry gas meter during period t (ft^3)

t = incremental sampling period (min.)

B_{wo} = volume proportion of water in stack gas

ΔH = orifice pressure differential during period t (in. H_2O)

T_s = absolute stack gas temperature during period t ($^{\circ}R$)

D_N = diameter of nozzle opening (in.)

T_m = absolute temperature at dry gas meter (average of temperatures at inlet and outlet) during period t ($^{\circ}R$)

P_s = absolute stack gas pressure (in. Hg)

U_s = stack gas velocity (ft/sec)(See eq. 2(4))

6. DISCUSSION OF METHOD 5

Purpose

This method is applied to determine the particulate concentration in an enclosed gas stream. A representative sample of stack gas and particulate is withdrawn isokinetically from the source using a heated probe, filter, condenser and metering devices. The particulate is collected on an out-stack glass fibre filter and in the front half of the sampling apparatus. This method is designed to collect particulates which are greater in size than 0.3 um at a temperature of $120^{\circ}C$ ($248^{\circ}F$). The Provincial Officer may require that particulates found in the back half of the sampling apparatus be included in the calculation of particulate emissions.

Limitations

As noted above, the standard temperature at which particulate is collected by this out-stack method is $120^{\circ}C$ ($248^{\circ}F$). It is assumed that normally particulate matter does not volatilize below that temperature. This temperature is selected so as to be above the boiling point of water yet not so high as to volatilize particulate. It is important to ensure that water does not condense on the filter and cause an excessively high pressure drop. However, there are sources which contain substances which can condense at temperatures above the standard, e.g. acid mist, and thus load the filter. For this reason and others, sources containing significant amounts of such substances may not be able to be sampled using the apparatus and procedure described in the method. Appendix 5B outlines some alternate approaches for use at sources where such conditions exist.

Sources which are not in continuous operation, e.g., batch operations, plant shutdowns of short duration, etc., can be sampled with some modifications to the procedure of this method. This is discussed in Appendix 5C.

Procedure

The steps of this procedure are separated into several sections, each section of activities being distinct by virtue of its position in the sequence of events and the physical location of the activity. Thus, the preparation procedures are performed in a laboratory, the preliminary survey is performed on site but usually at least a day before the actual testing, the sampling apparatus preparation and sample recovery are done usually in both the laboratory and on site and the analytical procedures are performed in a laboratory at some time after the actual testing.

The procedure is designed so that a representative sample will be obtained. Therefore, care must always be taken to ensure that all the components are properly cleaned and that no extraneous matter is picked up in the nozzle or on the filter. Also, the cleanup procedure must be done scrupulously and leak-checks must always be performed to ensure that only stack gas is being sampled.

To ensure that the sample is representative, it must be drawn at an isokinetic rate, i.e., the velocity of the gas upon entering the nozzle equals the velocity of the gas stream in the stack at the sampling point. This requirement is necessary, because aerodynamic and inertial effects will cause an overestimation of the particulate concentration, if sampling subisokinetically, or an underestimation for superisokinetic sampling.

Method 5 incorporates the apparatus and procedures of Method 4 and reference should be made to that method for equations and calculations to determine the moisture content. For each Method 5 test a moisture content analysis and molecular weight analysis (Method 3) must be performed.

7.   SAMPLE CALCULATIONS

Sample data for one traverse are recorded in Figure 22. Normally a second traverse is done and calculations are based on total sample volume and moisture for both traverses. Respective portions of these data have been used in the sample calculations in Methods 2 and 4. Moisture and particulate collection data are recorded in Figure 23.

FIGURE 22. FIELD SAMPLING REPORT

Plant*
Location*
Date*
Operators*
Run No.*
Pitot Coefficient* 0.762
Dry Gas Meter Correction Factor* 1.0
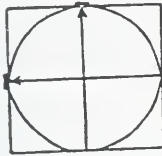
Ambient Temperature (°C)* 23°C
Atmospheric Pressure, P bar (in. Hg)* 29.73
Assumed Moisture (%)* 11.0
Static pressure, P static (in. H_2O)* - 0.4
Stack Diameter (ft)* 3.58
Nozzle Diameter (in.)* 0.25
Probe Length (ft)* 6.0
Probe Liner* glass
Stack Gas Molecular Weight (lb/lb mole)*

Schematic of stack cross-section; indicating compass direction, orientation of traverses and upstream flow disturbances

Traverse Number and Direction - 1, N-S

Sampling Point Number	Sampling Time (Min.)	Stack Temp. T_s (°F)	Velocity Head ΔP (in.H_2O) Low	Velocity Head Avg.	Velocity Head High	Orifice Pressure Drop Δh (in.H_2O)	Gas Sample Volume, V_m (cu.ft.)	Dry Gas Meter Temp. Inlet T_M in (°F)	Outlet T_M out (°F)	Sample Box Temp. (°F)	Impinger Outlet Temp. (°F)	Probe Temp. (°F)	Vaccum (in.Hg.)
1	0	220				0.60	1734.39	70	70	250	65	250	3.0
	3	220		0.67		0.55	1736.46	71	70	250	65	250	3.0
2	6	250		0.67		1.35	1738.50	72	71	250	66	250	3.0
	9	250		1.55		1.35	1741.41	73	71	250	66	250	3.0
3	12	250		1.34		1.20	1744.17	73	72	250	66	250	3.0
	15	250		1.55		1.25	1747.23	74	72	250	66	250	3.0
4	18	250		1.65		1.20	1750.48	75	73	250	66	250	3.0
	21	250		1.55		1.20	1753.43	76	74	250	66	250	3.0
5	24	250		1.55		1.02	1756.28	77	74	250	66	250	3.0
	27	250		1.03		1.03	1758.73	79	75	250	66	250	3.0
6	30	250		1.03		1.04	1761.03	80	76	250	66	250	3.5
	33	255		1.03		1.03	1763.51	82	76	250	66	250	3.5
7	36	255		1.03		1.03	1765.90	83	77	250	66	250	3.5
	39	255		1.03		1.03	1768.19	85	77	250	66	250	3.5
8	42	250		1.03		1.02	1770.52	86	77	250	66	250	3.5
	45	250		1.03		1.02	1772.92	87	78	250	66	250	3.5
	48	250		1.03		1.00	1775.22						
		avg. 247.2				avg. 1.06		avg. 77.7	avg. 73.6				

* Information required for Method 5

FIGURE 23. Moisture and Particulate Catch Data

		final wt.(g)	tare wt.(g)	particulate wt.(g)
a)	Filter	1.1693	0.7381	.4312
b)	Beaker containing washings from nozzle, probe, cyclone (if used) and front half of filter holder	104.9649	104.6932	.2717
c)	Cyclone collection flask	100.5919	100.4931	.0988
d)	Beaker containing impinger contents and washings from impingers and back half of filter holder	101.5357	101.3682	0.1675

weighing room relative humidity: pre-test - 42% post-test - 39%	total wt. of particulate = 0.8.017 g. (excluding impinger contents) = 0.8017 g.

	final wt.(g)	tare wt.(g)	wt. of H_2O (g)
Impinger #1:	579.5	537.4	42.1
Impinger #2:	631.2	565.8	65.4
Impinger #3:	485.9	484.3	1.6
Impinger #4:	623.0	612.0	11.0
desiccant saturation level = 1/3		total wt. of H_2O = 120.1 g	

From the sample calculations of Method 2 and 4 the following parameters were determined:

$$U_{s(avg)} = 64.8 \text{ ft/sec}$$
$$Q_s = 1.55 \times 10^6 \text{ SDCF/hr}$$
$$B_{wo} = 0.124$$

assuming that a molecular weight of dry stack gas, M_d = 29.02 lb/lb-mole

$$M_s = 27.65 \text{ lb/lb-mole}$$

from the data given here:

$$\Delta H_{(avg)} = 1.06 \text{ in. } H_2O$$
$$T_{s(avg)} = 707.2 \text{ }^{\circ}R$$
$$T_{m(avg)} = 535.6 \text{ }^{\circ}R$$
$$P_s = 29.70 \text{ in. Hg}$$
$$V_M = 40.83 \text{ ft}^3$$

$$P_{m(avg)} = P_{bar} + \frac{\Delta H_{(avg)}}{13.6}$$

$$= 29.73 + \frac{1.06}{13.6}$$

$$= 29.80 \text{ in. Hg}$$

$$V_{m(ref)} = \frac{17.95 \text{ } \gamma \text{ } P_{m(avg)} \text{ } V_m}{T_{m(avg)}}$$

$$= \frac{17.95 \text{ } (1.0) \text{ } (29.80) \text{ } (40.83)}{535.6}$$

$$= 40.77 \text{ ft}^3$$

NOTE: In comparing the calculated values of $V_{m(ref)}$ in this example and
in Method 4, there is a slight discrepancy which is explained by
the fact that it is permissible to use $P_m = P_{bar}$ for moisture determination
whereas for this method P_m must be the true value which is $P_{bar} + \frac{\Delta H}{13.6}$

However, the slight difference between the two values does not significantly
alter the value of B_{wo} or M_s.

particulate concentration,
$$C_s = \frac{(2.205 \times 10^{-6})M_p}{V_{m(ref)}}$$

$$= \frac{(2.205 \times 10^{-6})(801.7)}{40.77}$$

$$= 4.34 \times 10^{-5} \text{ lb/ft}^3$$

emission rate, $\quad ER_p \quad = C_s Q_s$

$\qquad\qquad\qquad = (4.34 \times 10^{-5})(1.55 \times 10^6)$

$\qquad\qquad\qquad = 67.3 \text{ lb/hr}$

percentage isokinetic sampling rate,

$$\%I = \frac{T_s(\frac{DGMV}{3})(\gamma)(\frac{1}{1 - B_{wo}})(P_{bar} + \frac{\Delta H}{13.6})(100)}{0.3272 \, T_m \, P_s \, U_s \, D_N^{\,2}}$$

for the first point, first reading:

$$\%I = \frac{680(\frac{2.07}{3})(1.0)(\frac{1}{0.876})(29.73 + \frac{0.60}{13.6})(100)}{(0.3272)(0.25)^2(530)(29.70)(85.35)(0.762)\sqrt{\frac{(680)(0.67)}{(29.70)(27.65)}}}$$

$$= 102.3\%$$

In Figure 24 there are listed the calculated velocities and percentage isokinetics for the sample points.

Sampling Point Number	Velocity (ft/sec)	%I
1	48.4 48.4	102.3 100.7
2	75.3 69.99	96.5 98.4
3	75.3 77.7	104.4 104.4
4	75.3 75.3	97.8 94.5
5	75.3 71.4	94.5 99.6
6	61.4 61.6	93.5 101.2
7	61.6 61.4	93.5 94.8
8	61.4 61.4	97.6 93.5
	AVG. 64.8	AVG. 98.1

FIGURE 24. Calculated velocities and percentage isokinetics

APPENDICES TO METHOD 5

Appendix 5A - Determination of nozzle size and setting isokinetic sampling rates

As stated in this method, it is necessary to sample at a rate such that the velocity of the gas entering the sampling nozzle equals the velocity of the undisturbed gas at the sampling point. The ratio of nozzle to stack gas velocity must be 100% ± 10%. This ratio is calculated using the stack gas conditions at the time of sampling. Since some of these conditions such as mositure content can only be determined after the test, it is necessary to estimate them as closely as possible for the purposes of choosing the proper nozzle size, for the preparation of tables to facilitate the setting of isokinetic rates and checking the rate at the time of sampling, using eq. 5(5) or eq. 5(10).

A nozzle size must be determined so that it is neither too large, i.e., beyond the ability of the train to draw sample isokinetically at high ΔP's, nor too small, i.e., requiring an impractically small ΔH setting at low ΔP's. The smallest (practical) nozzle is .9 mm (0.1875 inch) in diameter.

Nozzle Size Determination

One method for determining the proper nozzle size is as follows:

for true isokineticity: $\dfrac{\text{velocity in nozzle}}{\text{velocity in stack}} = 1$

from that:

$$\Delta H = \left(\frac{60(85.35)(\pi) D_N^2 C_p}{4(144)} \right)^2 \frac{(1 - B_{wo}) M_d T_{m(avg)} P_s \Delta P}{K_o^2 M_s T_{s(avg)} P_m} \quad \text{eq. 5(11)}$$

where
$\quad D_N \quad = \quad$ nozzle diameter (in.)
$\quad C_p \quad = \quad$ pitot coefficient
$\quad B_{wo} \quad = \quad$ moisture content
$\quad M_d \quad = \quad$ dry stack gas molecular weight (lb/lb-mole)
$\quad M_s \quad = \quad$ stack gas molecular weight (lb/lb-mole)
$\quad T_{m(avg)} \quad = \quad$ average temperature at orifice ($^{\circ}$R)
$\quad T_{s(avg)} \quad = \quad$ average stack gas temperature ($^{\circ}$R)

$$P_s \quad = \quad \text{absolute stack gas pressure} \simeq P_{bar} \text{ (in. Hg)}$$
$$P_m \quad = \quad \text{absolute orifice pressure} \simeq P_{bar} \text{ (in. Hg)}$$
$$K_o \quad = \quad \text{orifice coefficient}$$

NOTE: For determination of metric nozzle sizes substitute
1.0×10^4 for 144, 128.6 for 85.35 and the respective S.I.
values of the variables in the above formula.

These values are estimated or calculated, usually being based on experimental values from a preliminary survey (the nozzle used for that test is picked by approximation). By substituting numerical values for all of the variables of the equation except ΔH, D_N and ΔP, a value for K in the following equation may be determined:

$$\Delta H = \Delta P K D_N^4 \qquad \qquad \text{eq. 5(12)}$$

Having determined K, to obtain the correct nozzle diameter:

    i)   choose for ΔH the maximum ΔH obtainable or readable from the sampling train

    ii)   choose for ΔP the maximum obtained or expected based on the preliminary survey

    iii)   by rearranging the above equation so that:

$$D_N = \left(\frac{\Delta H}{K \Delta P}\right)^{\frac{1}{4}} \qquad \qquad \text{eq. 5(13)}$$

          and substituting accordingly, D_N may be calculated

    iv)   the nozzle size next smaller to the calculated D_N is the appropriate size

Isokinetic Sampling Rate Determination

There are several methods used to determine isokinetic sampling rates. One method is as follows:

    i) if the variables of the above equations are determined at a particular instant the following relationship is found:

$$\Delta H = \frac{k' \, \Delta P \, T_m}{T_s} \qquad \qquad \text{eq. 5(14)}$$

where
$$k' = \frac{T_{s(avg)} \, KD_N^{\;4}}{T_{m(avg)}}$$

T_m = instantaneous absolute meter temperature

T_s = instantaneous absolute stack gas temperature

ii) calculate k'

iii) if $k'' = k' \, (T_m/T_s)$ by substituting expected values of T_m and T_s a table of values for k'' may be prepared

iv) the above equations simplify to:

$\triangle H = k'' \triangle P$ and therefore, during sampling, upon determining $\triangle P$ at a sampling point, the meter temperature and the stack gas temperature and using the prepared table, k'' will also be known and thus the correct $\triangle H$ can be calculated.

Another common method is the use of nomographs, usually commercially prepared. Nomographs are easy to operate and are reasonably accurate. However, most nomographs are pre-set for a pitot coefficient of 0.85 and manufacturers instruction on the use of these nomographs can be modified so that the location of pivot point will correspond to true coefficient; $\triangle P$ is multiplied by $C_p/.85$ and the new $\triangle P$ used to set the pivot point. As well, the nomograph must be readjusted during sampling as the meter temperature and stack gas temperature change.

Appendix 5B - Gas streams having significant concentrations of substances with dew point greater than 120°C (248°F)

There is an almost infinite variety of sources and components of gas streams. Some components may have dew points above 120°C (248°F), i,e., above the probe and filter heater temperature. The concentration of the component is significant if the component condenses on the filter and this condensate causes such a high pressure drop that the pump is unable to draw at isokinetic rates. To overcome this problem, the probe and filter must be maintained above the dew point of the component. However, increasing the temperature may volatilize some or all of the particulate thus allowing it to pass through the filter to be caught in the impingers. In such cases it may be necessary to install an additional backup filter after the impingers and include the impinger catch and the particulates on the backup filter in the calculation of emission rate.

Another problem possibly encountered with increasing the filter temperature is that reactions may occur on the filter itself which may result in a nonrepresentative particulate sample.

The Provincial Officer should be contacted where there is a problem of condensible components so that an appropriate sampling methodology can be agreed upon.

Appendix 5C - Non-continuous sources

Some sources are noncontinuous by their nature, e.g., batch processes. As well, some processes slow down or stop at certain times, e.g., lunch break or process interruptions. When this type of problem occurs it is necessary to halt sampling, remove the probe and cover the nozzle and then to recommence sampling when the process operations return to their usual level.

Since noncontinuous processes pose problems with respect to sampling and cannot be generalized, the Provincial Officer should be contacted to discuss the particular situation.

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